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TECHNOLOGY ASSESSMENT FOR RADIONUCLIDE REMOVAL REPORT - TRD-075-94

Action: None Required

A copy of the Technology Assessment for Radionuclide Removal (TARR) report, as completed for Task 1200 of the Fiscal Year (FY) 1995 Onsite Water Management Work Package 12852 has been provided for your review. Wright Water Engineers, Inc. was commissioned by the EG&G Rocky Flats, Inc. Surface Water Division to provide this product.

The general objectives of this report were to document the performance of current technologies used to remove radionuclides from water, to evaluate performance tests on potentially applicable emerging technologies, and to identify information gaps in radionuclide treatment technologies for which further research may be warranted. A preliminary methodology for treatment selection was developed for generation of three basic treatment schematics to treat permitted surface water discharges.

The TARR will be used as a prerequisite guidance/support document in developing the Pond Water Treatment Implementation Plan scheduled for FY 1995 in the Rocky Flats Environmental Technology Site (Site) Pond Water Management Work Package 61211. The TARR is also a management tool to assist in water treatment decisions for the Site in the event the water quality does not meet environmental low-level radionuclide discharge conditions.

If you have any questions please contact Ed Moritz at extension 3716.

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TECHNOLOGY ASSESSMENT FOR RADIONUCLIDE REMOVAL

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LIST OF ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Is Reasonably Achievable
ATTIC	Alternative Treatment Technology Information Center
AWQC	Ambient Water Quality Criteria
AWWA	American Water Works Association
BAT	Best Available Technology
CARL	Colorado Alliance of Research Libraries
CDH	Colorado Department of Health
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFPM	Colloid Filter Polishing Method
CFR	Code of Federal Regulations
CLU-IN	Clean Up Information Bulletin Board
CWA	Clean Water Act
DEQ	Department of Environmental Quality
DOE	U.S. Department of Energy
DRG	Derived Concentration Guide
EDTA	Ethylenediaminetetra-acetate
EFF	Effluent
EPA	U.S. Environmental Protection Agency
ETF	Effluent Treatment Facility
FEMP	Fernald Environmental Management Project
GAC	Granulated Activated Carbon
GRRASP	General Radiochemistry and Routine Analytical Services Protocol
INF	Influent
INT	Intermediate
ITPH	Interceptor Trench Pump House
IX	Ion Exchange
LANL	Los Alamos National Laboratory
LLRLW	Low-Level Radioactive Liquid Waste
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDA	Minimum Detectable Activity
MDL	Method Detection Limit
MPE	Magnetic Polyamine-Epichlorohydrin
MW	Molecular Weight
NORM	Naturally Occurring Radioactive Materials
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NTA	Nitrolotriacetate
NTIS	National Technical Information Service
O&M	Operation and Maintenance

LIST OF ACRONYMS AND ABBREVIATIONS, continued

ORD BBS	Office of Research and Development Bulletin Board System
OU	Operable Unit
PDL	Public Dose Limit
PE	Performance Evaluation
PPB	parts per billion
PQL	Practical Quantitation Limit
RDL	Required Detection Limit
RFETS	Rocky Flats Environmental Technology Site
RO	Reverse Osmosis
RREL	Risk Reduction Engineering Laboratory Treatability Database
RRS	Radionuclide Removal System
SAC	Strong Acid Cation
SBA	Strong Base Anion
SDWA	Safe Drinking Water Act
SITE	Superfund Innovative Technology Evaluation
T&C	Technology and Cost
TDS	Total Dissolved Solid
VISITT	Vendor Information System for Innovative Treatment Technologies
WQCC	Water Quality Control Commission

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TECHNOLOGY ASSESSMENT FOR RADIONUCLIDE REMOVAL

EXECUTIVE SUMMARY/ABSTRACT

Performance data for existing water treatment technologies and research reports and treatability studies for emerging technologies are investigated to determine the state of the practice for removal of picocurie and sub-picocurie levels of radionuclides from natural waters. Radionuclides of specific interest are plutonium, americium, and uranium, as well as general gross alpha and gross beta activity. Associated fate and transport mechanisms, analytical limitations, and regulatory issues are also discussed. Technologies for americium and plutonium which are capable of achieving stringent water quality standards are unproven on a full scale basis. Technologies for uranium, gross alpha, and gross beta capable of meeting imposed water quality standards are available. For low and intermediate flow rates (below 250 gpm), recommended unit processes for removal of mixed radionuclides in an environmental setting include enhanced sub-micron filtration and reverse osmosis. At high flow rates, the conventional technologies of coagulation-precipitation/filtration and lime softening are recommended for pretreatment, with final treatment by ion exchange, reverse osmosis and adsorptive processes depending on the specific radionuclides of interest. Technologies recommended for further study include bone char adsorption, magnetic filtration and enhanced submicron ultrafiltration.

CHAPTER 1

INTRODUCTION

1.1 GOALS AND OBJECTIVES OF THE REPORT

The general objectives of this report are to document the performance of current technologies used to remove radionuclides from water, to evaluate performance tests on potentially applicable emerging technologies, and to identify information gaps in radionuclide treatment technology for which further research may be warranted. The specific goal of this report is to identify and select treatment technologies capable of achieving a 0.05 pCi/L effluent concentration for plutonium and americium, a 5 pCi/L effluent concentration for uranium and gross beta, and a 7 pCi/L effluent concentration for gross alpha.

The report presents three conceptual-level schematic diagrams of potential radionuclide removal treatment systems. These schematics are made up of individual unit processes which have the greatest potential to successfully treat environmental levels of radionuclide contamination in water. Individual unit processes are detailed within the report, and include conceptual-level capital and operating cost estimates.

This report is intended to provide supporting baseline information to be used in developing a strategy for upgrading surface water treatment capabilities at the Rocky Flats Environmental Technology Site (RFETS). An important part of this strategy is to select and install appropriate technologies for removal of radionuclides from stormwater flows and other incidental surface waters in order to meet stringent water quality criteria for water discharges from RFETS. Although it is hoped that other programs will be able to use the information presented herein, the report focuses on short-term, non-routine treatment of surface water rather than as a permanent (or continuously operated) remediation technology for groundwater or soils.

1.2 PROBLEM STATEMENT

In 1990, stringent stream standards for radionuclides were promulgated by the Colorado Water Quality Control Commission (WQCC) for the stream segments on and downstream of RFETS. These new radionuclide standards established maximum ambient concentrations for general gross alpha and gross beta water contamination below previously existing federal guidance, and set stringent new standards for plutonium, americium, and uranium that did not previously exist. To comply with these new standards, a potential need to treat water effluent for radionuclides at sub-

picocurie levels was identified. This report will address that need by answering the following questions:

1. What are the conventional treatment technologies used for gross alpha, gross beta, and uranium removal, and what is their performance?
2. Are specific treatment technologies available for plutonium and americium that are capable of achieving the 0.05 pCi/L standard?
3. What research has been conducted on emerging or modified radionuclide removal technologies, and what are the performance results?
4. Which of these emerging technologies or modified process configurations warrant further research?
5. What unit processes and system configurations appear most appropriate for installation at RFETS given historic water quality and expected usage?

1.3 ASSESSMENT APPROACH

Preparation of this report began with searches of computerized databases for potentially applicable reports, articles, textbooks, conference proceedings, government (particularly EPA) publications, and other published material. Search parameters included the words radionuclides, removal, treatability, treatment, uranium, plutonium, americium, alpha, beta, technology, and water in various combinations. Electronic sources were accessed through DIALOG, an on-line computer system, allowing searches in a wide range of individual databases. Searches included the following publicly available databases and bulletin boards:

VISITT - Vendor Information System for Innovative Treatment Technologies (EPA)
CLU-IN - Clean Up Information Bulletin Board (EPA)
ORD BBS - Office of Research and Development Bulletin Board System (EPA)
ATTIC - Alternative Treatment Technology Information Center (EPA)
NTIS - National Technical Information Service
RREL - Risk Reduction Engineering Laboratory Treatability Database (EPA)
CARL - Colorado Alliance of Research Libraries
EPA National Catalog

Database searches were followed up with library searches at the Colorado School of Mines, University of Colorado-Boulder, Denver Public Library, EPA Region VIII library, and the RFETS Environmental Library to retrieve copies of reports and articles and check for other reference sources. Journals such as *Environmental Science and Technology* and the *Journal of the American waterworks Association* proved particularly useful, as did the RFETS library, which contained numerous research reports and treatability studies on radionuclides not available in general circulation.

Additional information was obtained from the American Water Works Association (AWWA) research branch, individual mining companies, U.S. Nuclear Regulatory Commission (NRC) and U.S. Department of Energy (DOE) documents, equipment and treatability study vendors, and from remediation professionals at various sites throughout the DOE weapons complex. Individual researchers in the field of radionuclide removal were also contacted by phone to get their opinions on the state of the art, promising new technologies, and current research. Although time constraints did not allow an "expert panel" to be convened for this report, many of the researchers contacted would be suitable for such a panel should this be desired in the future.

Research on performance data for existing and emerging technologies consisted of literature reviews and evaluation of published journal articles, government guidance documents (i.e., the U.S. Environmental Protection Agency [EPA], DOE, NRC), draft and final treatability studies, published research reports, and vendor information. Additional performance information was obtained via telephone contacts or personal interviews with equipment vendors, remediation engineers and managers, treatment plant personnel and with private and public researchers.

Background information on regulatory issues, water quality standards, limitations of analytical methods, and ambient water quality was obtained from state and federal documents (CWQCC 1993; FR 1991) and from specific RFETS documents (DOE 1993a; DOE 1994b) submitted to the agencies to fulfill regulatory requirements. Background information on the occurrence, fate, and transport of radionuclides in the environment was obtained from specific RFETS documents and from various literature sources. Background information on the chemistry of radioactive elements, and on generic treatment process descriptions were obtained from textbooks and various literature sources.

Evaluation of technologies for removal of environmental levels of radionuclides from surface waters requires a thorough knowledge of the occurrence and behavior of these radionuclides in a natural setting, and an estimate of probable concentration levels. A review of the current

assumptions pertaining to the physical and chemical properties of the actinide elements was conducted to establish this knowledge base and to guide subsequent evaluation of potential removal technologies. This review was used to determine the probable chemical form, speciation and particle size range of radionuclides potentially present in the water column. A secondary objective of this review was to determine whether certain removal technologies might apply to several different radionuclides. For this purpose, it was necessary to ascertain what similarities in separation chemistry are exhibited by the different radionuclides of interest here.

Activity levels corresponding to various isotopes and particle size ranges were also investigated. Chemistry reference data and EPA guidance documents were reviewed to determine those elements that significantly contribute to general gross alpha and gross beta radioactivity. Published water quality/water chemistry data for RFETS surface water was evaluated to establish estimated maximum influent radionuclide concentration levels for which treatment would be required, and to establish corresponding removal efficiencies necessary to achieve imposed water quality standards.

Both current and emerging technologies were subjected to a formal screening and selection process to determine the potential applicability of the technology to RFETS. Criteria applied in the screening process followed the general guidance found in EPA CERCLA (EPA 1988, 1990) documents and in the RFETS *Treatability Studies Plan* (DOE 1991b) but were modified to reflect a focus on current application of these technologies specifically to radionuclides rather than as general remediation technologies. Final selection of technologies and unit processes for inclusion in the schematic process diagrams was based on the results of the screening process and on a comparative evaluation implementation difficulties and adverse waste impacts.

1.4 LIMITATIONS OF REPORT

The main focus of this report is on radionuclides with specific interest to RFETS, americium, plutonium, and uranium. Existing and emerging technologies for the treatment of all types of man made and naturally occurring water-borne radionuclides, represented as general gross alpha and gross beta contamination, are also evaluated.

Current and emerging technologies were evaluated based on published research reports, published performance data, and expert opinion. No attempt was made to verify performance data or conduct independent testing of technologies, nor was any attempt made to evaluate the technical credibility of the research results. Consequently, the report does not make any conclusions

regarding the potential viability of technologies which have undergone bench testing, but for which no pilot scale or full scale performance data is available. However, promising technologies which warrant further research are discussed in the recommendations section at the end of this report.

Removal efficiencies for various technologies researched at pilot or full scale are cited as published. No attempt was made to evaluate whether process controls employed in a particular research project were adequate to ensure the reliability of the performance data; however, analytical limitations associated with accurately measuring low level radionuclide concentrations are noted, as appropriate.

Capital and operating costs given for specific technologies, unit processes, and/or system arrangements are conceptual, and are based on information obtained for operations personnel, published "average" or "typical" costs cited in the literature, or in some cases from equipment vendors. No attempt has been made to account for the variability in labor costs and markups applicable to government facilities versus private industry.

CHAPTER 2

BACKGROUND

This chapter of the report provides the background information necessary to describe and evaluate current and potential future technologies for removal of radionuclides from RFETS waters. Included in this chapter is a discussion of the following topics: (1) occurrence and behavior of radionuclides in the environment which, in turn, guide the design and selection of potential removal technologies; (2) a discussion of analytical limitations and regulatory requirements which drive implementation of these technologies; (3) a summary of current water quality from which maximum probable radionuclide concentration levels can be estimated, and for which required removal efficiencies can be calculated; and (4) a general description of water treatment unit processes and their application to removal of radionuclides.

2.1 OCCURRENCE, FATE, AND TRANSPORT OF ACTINIDES IN THE ENVIRONMENT

From the viewpoint of removing low concentrations of radionuclides, particularly the actinides, from water, the main conclusions to be drawn from the more detailed discussion which follows are:

1. Radionuclides can be mobile in water even though they may be in an insoluble form, because a large fraction tends to occur as very small particles (less than 0.2 μm) which are smaller than the standard 0.45 μm particle size generally considered to be settleable. These small particles adsorb quickly to other solids, in particular non-settleable colloidal-sized solids, which can keep them in suspension.
2. Although unproven, the literature indicates that the truly dissolved portion of radionuclides also quickly becomes strongly adsorbed to colloidal ("colloidal pumping") and sediment (sorption) surfaces. If the colloidal content is large, it can contain most of the radioactivity of a surface or groundwater system. As a result, simple filtering as a pretreatment step may not be effective at removing radioactivity from water systems with high organic colloid and/or mineral colloid content (colloidal pumping is defined as humic and fulvic materials and clays).
3. Because complexation is usually decreased under reducing conditions, solubility is also usually decreased and adsorption increased.

4. A possible strategy for treatment that makes use of colloidal pumping might be the following:
- Within the water to be treated, create an in situ colloidal precipitate of, for example hematite ($\alpha\text{-Fe}_2\text{O}_3$), to offer a large surface area for adsorption. The oxidation potential here should be low to establish reducing conditions. If there is a high colloidal organic component to the water, pretreatment with CaCO_3 might be desirable, since CO_3^{2-} tends to displace organic complexing ions around pH 7 to 8.
 - After sorption is essentially complete, perhaps about 30 minutes, adjust the pH to an empirically determined optimum value and introduce a flocculant. There are indications in the literature that an optimum pH might be around pH 7.
 - Follow with sequentially finer filtering.
 - If necessary, polish with ion-exchange, reverse osmosis, or activated carbon.

2.1.1. OCCURRENCE OF ACTINIDES IN THE ENVIRONMENT

General

Transuranium elements in the environment mostly exist in a strongly adsorbed state on surface soils. The physical transport of these elements is primarily due to wind and water movement. In water, americium, and curium remain in the +3 oxidation state over the normal range of environmental conditions. The chemistry of plutonium and neptunium is more complex because they display multiple oxidation states in aqueous solutions within the range of natural concentrations (Seaborg and Loveland 1990).

Insoluble forms of the actinides present in surface and groundwaters tend to precipitate as micron and submicron sized solids which sorb strongly to other solids present in the water. Even the dissolved forms tend to be sorbed to solids because they are attracted by ionic forces to colloidal-size solids. Actinides that are partitioned to colloids and fine sediments are mobile in this form until coagulation and flocculation processes cause settling and immobilization.

Thorium and Uranium

Uranium and thorium are preferentially incorporated into late crystallizing magmas and residual solutions because their large ionic radii preclude them from early crystallizing silicates such as olivine and pyroxenes (Ivanovich and Harmon 1982). They are therefore found associated mainly with granites and pegmatites. Radium, when naturally fractionated from parent thorium-230, is found in hydrothermal precipitates such as barite and in association with lead deposits. Many radium salts are insoluble, particularly the sulfate and carbonate.

In the oxidized zone of soil near the surface, U and Th may both be mobilized, but in different ways. Thorium is almost always bound in insoluble resistate minerals or is adsorbed on the surface of clay minerals (*ibid*, page 36). By contrast, U may move in solution as a complex ion or, like Th, in a detrital, resistate phase. Both elements occur in the +4 oxidation state in primary igneous rocks and minerals, but U, unlike Th, can be oxidized to the +5 and +6 states in the near surface environment. The +6 state of U is the most stable and forms soluble uranyl complex ions (UO_2^{+2}) which play the most important role in U transport during weathering.

Uranium is strongly enriched in certain organic sediments, particularly those formed from humic substances such as peat, lignite and coal (*ibid*, page 39). Humics are particularly effective in adsorption of the cations of Th and U from water. Organic deposits formed from bituminous and sapropelic materials (hydrocarbons such as resins, algae, spores, and lipids) contain little U. Fixation of U as uranyl humate or fulvate by cation exchange is thought to be the concentrating process in humic substances. Peat and lignite have been found to adsorb U from groundwaters with a partition coefficient as high as 10^4 (*ibid*, page 44).

Uranyl humates are insoluble in the pH range 2.2 to 6, with maximum adsorption of U occurring at about pH 4 to 5 (*ibid*, page 44). Uranyl fulvates are insoluble in the pH range 6 to 6.6. It is clear that small changes in pH can mobilize, transport, and reprecipitate U. There is evidence that carbonate and phosphate ions can displace organic complexing ions at pH 7 to 8.

Once complexed by organics, the uranyl ion may be subsequently reduced to the uranous state if the oxidation potential becomes reducing in the sediment environment. The decomposition of organic materials may form H_2S , which also can reduce uranyl compounds to form UO_2 (*ibid*, page 39).

In distilled water, the solubility of uraninite is less than 0.01 ppb between pH 2 and 7. In the oxidized form of the uranyl ion (UO_2^{+2}), and in the presence of complexing ions, the solubility increases by several orders of magnitude. Surface waters typically contain U in the range 0.01 to 50 ppb and groundwaters in the range 0.1 to 50 ppb, but reaching 500 ppb in mineralized areas (ibid, page 40). An empirical relation has been derived for the concentrations of U in solution (U_s) and in bedrock (U_r) and total dissolved solids in the water, from a study of over 1000 waters in the USSR (Lopatkina 1964):

$$U_s (\text{ppb}) = 0.002 \times U_r (\text{ppm}) \times \text{TDS} (\text{ppm})$$

The only uranous (+4) species with appreciable solubility in natural waters are fluoride and hydroxyl complexes at low Eh conditions, up to 1 ppb U for 0.2 ppm total F^- at pH 2. Uranyl complexes (+6) are far more soluble than uranous species. The dominating form depends on the pH-Eh conditions. Soluble complexes are formed with carbonate, phosphate, sulfate, fluoride, and silicate ions. Under natural conditions, the most important uranyl forms are: the free uranyl ion below pH 3, fluoride between pH 3 to 4, phosphate between pH 4 to 7.5, and carbonate above pH 7.5. Silicate complexes can form at about pH 6, but are insignificant in natural waters. Sulfates are only formed in low concentrations below pH 4 (Ivanovich and Harmon 1982).

If U is present in solution as a carbonate complex, lowering the partial pressure of CO_2 by degassing groundwater when it is exposed to the surface, will cause the U to precipitate, usually in the form of a coprecipitate with other minerals. The ready ability of U to undergo inorganic dissolution and reprecipitation is probably the most important mobilizing process in the natural environment.

Not all the U present in igneous rocks is taken into solution during the weathering process. Some is tightly bound into accessory minerals which are resistant to chemical attack (resistates). For instance, zircon grains may contain up to 6000 ppm U, little of which is lost during weathering, transportation, and deposition.

The thorium content of natural waters is extremely low, thorium-232 ranging from less than 8×10^{-6} to 0.1 ppb for sea waters (ibid, page 40). Because of its very low solubility in most natural waters, Th is almost entirely transported in particulate matter. Even when Th is generated in solution by radioactive decay of U, it rapidly hydrolyzes and adsorbs onto the nearest solid surface.

Plutonium

Over 99 percent of plutonium released to the environment ends up in the soil and in sediments. The global average concentration of plutonium in soils is between 5×10^{-4} and 2×10^{-2} pCi/g, with most of the plutonium being near the soil surface (top 15 cm) (Seaborg and Loveland 1990). In water, the average concentration of plutonium is about 10^{-4} pCi/L. Greater than 96 percent of plutonium released to an aquatic ecosystem ends up in the sediments. Particle size analysis in Cumbrian soils (Bulman and Cooper 1985) showed enrichment of Pu in the finer fractions (less than 2 μ m), particularly in clay material. Most of the Pu was associated with the organic components of the soils. Pu(III) and Pu(IV) were the only oxidation states observed presumably because of the reducing ability of the organic materials in the soil.

In aquatic sediments, there is some translocation of plutonium to the sediment surface due to the activities of benthic biota. Less than 1 percent (and perhaps closer to 0.1 percent) of all plutonium in the environment ends up in the biota. The percentage of plutonium in vegetation ranges from 10^{-5} percent to 2 percent, in ground surface litter from 10^{-4} percent to 2 percent, and in animals from 10^{-8} percent to 1 percent.

The possible oxidation states of plutonium are Pu(III), Pu(IV), Pu(V), and Pu(VI). Pu(III), Pu(V), and Pu(VI) are unstable under normal environmental conditions, so the +4 state is more commonly observed. Pu(IV) is the most stable in water that contains significant amounts of organic material, while in the absence of organic reductants which is uncommon in environmental systems, Pu(V) is the stable state. Humic materials will cause a slow reduction of Pu(V) to Pu(IV) (ibid, page 297).

Neptunium

Neptunium may exist as either Np(IV) or Np(V). Under reducing conditions, neptunium should be present as Np(IV) and behave like Pu(IV). Under oxidizing conditions, NpO_2^+ will be the stable species (ibid, page 297).

2.1.2 IMPORTANT FATE AND TRANSPORT MECHANISMS

Hydrolysis

All metal cations in water undergo hydrolysis to form hydrated species (Seaborg and Loveland 1990). The more highly charged the cation, the stronger the interaction with water. Hydrated cations of the transuranium elements, especially the +3 and +4 cations, undergo extensive hydrolysis and act as acids in solution, releasing protons to the solution and converting water molecules in the hydration sphere to hydroxyl and oxygen ions. Thus, metal hydroxides and oxides form, often of low solubility. The +4 cations have the greater charge-to-radius ratio and hydrolyze more readily. U(IV) undergoes hydrolysis in solutions of pH greater than 2.9, with $\text{U}(\text{OH})_3^+$ being the principle hydrolyzed species. Pu(IV) hydrolyzes extensively in moderately acid solutions and may form polymers.

Chemical Complexation/Chelation

Complexing agents form coordination bonds (a non-bonding electron pair on the complexing species is shared with an empty electron orbital on the metal cation to form the bond) with dissolved ionic radionuclides. Many organic complexing molecules (e.g., humic substances) have multiple sites capable of forming coordination bonds and can incorporate a radionuclide cation into a heterocyclic ring structure, a process called chelation. Naturally occurring chelating agents, such as humic substances and amino acids, are found in water and soil. Synthetic chelating agents such as sodium tripolyphosphate, sodium ethylenediaminetetra-acetate (EDTA), sodium nitrolotriacetate (NTA), and sodium citrate are produced in large quantities for use in metal-plating baths, industrial water treatment, detergent formulations, and food preparation.

Complexes of metal cations are often soluble and can resist the reactions that lead to metal precipitation. Thus, the presence of complexing agents in water from which radionuclides must be removed complicates the separation procedures. Complexation can have a number of effects in addition to increased solubility of metals, including oxidation-reduction, decarboxylation, and hydrolysis reactions (Manahan 1991). Complexation may cause changes in oxidation state of the metal and may result in a metal becoming solubilized from an insoluble compound. In some cases, the formation of insoluble complex compounds serves to remove metal ions from solution.

Chelates formed by the strong chelating agent EDTA have been shown to greatly increase the migration rates of radioactive cobalt-60 from pits and trenches used by the Oak Ridge National

Laboratory in Oak Ridge, Tennessee for disposal of intermediate level radioactive waste (Means 1978). In addition to cobalt, EDTA strongly chelates radioactive plutonium and radioisotopes of Am^{3+} , Cm^{3+} , and Th^{4+} , to form negatively charged soluble anions. Such chelates with negative charges are much less strongly sorbed by mineral matter and are much more mobile than unchelated metal ions.

2.2 GROSS ALPHA AND BETA ANALYSES

The significance of gross alpha and gross beta measurements is site and method specific. For example, waste streams from hospitals, research laboratories, drinking water treatment plants, and ore processing operations are all likely to have very different radionuclide profiles. Gross alpha and gross beta measurements are used as general screening techniques. If they exceed certain established levels (15 pCi/L gross alpha, 50 pCi/L gross beta) then further analysis is required to identify the specific isotopes responsible for most of the activity (EPA 1980).

Gross Alpha Analysis

Gross alpha activity is intended to be a measure of all the alpha emissions from all the contributing alpha emitters in the sample. Depending on the amount of care taken in the analysis, the gross alpha count may overestimate or underestimate the true alpha activity present in the water phase. An overestimate can occur if the water sample contains excessive amounts of sediment, because the alpha emitters thorium, plutonium, americium, polonium, and bismuth are mostly in insoluble forms and are concentrated in the sediments. An underestimate can occur if the water sample contains large amounts of dissolved salts, whether or not they are radioactive. A high dissolved salt content creates large amounts of sample residue in the evaporation process, which may attenuate part of the alpha activity.

When the concern is primarily with naturally occurring radioactive materials (NORM) in water, the main contributors to gross alpha activity are usually uranium and radium. These elements are the most abundant radionuclides in the uranium-238 decay chain that have common soluble forms, and their longer half-lives cause them to accumulate to higher abundances. At certain locations, thorium may also contribute significantly to gross alpha levels. Radon gas is not detected because the methods for gross alpha measurements involve evaporating the water samples and analyzing the residual solids (EPA 1980), a process that releases radon to the atmosphere.

EPA Method 900.0 is used for gross alpha when the dissolved solids content is not high and the uranium contribution to the gross alpha count is desired. Water supplies with high concentrations of dissolved solids often have high gross alpha activity (greater than 15 pCi/L) and uranium is frequently the source of most of the alpha emissions. The drinking water standard, however, specifies a gross alpha limit with the uranium contribution removed. For such waters with high dissolved solids, EPA Method 900.1, which separates the radium from the uranium isotopes, is the recommended procedure. With Method 900.1, a gross alpha analysis of NORM is essentially a measure of the total radium alpha activity.

At locations where man-made radioisotopes are of concern, neptunium, plutonium, americium, and curium might be additional contributors to gross alpha activity. At RFETS, the largest sources of alpha activity in the terminal ponds are naturally occurring uranium and its decay product radium (Efurd 1993). Anthropogenic depleted uranium accounted for about 20 percent of the total uranium in Pond B-5 and about 50 percent of the total uranium in Ponds A-4 and C-2. Table 1 shows average distributions in the terminal ponds of the isotopes contributing to gross alpha measurements. The average percentages were calculated from selected reference data (Efurd 1993).

Gross Beta Analysis

Gross beta activity is a measure of all the beta emissions from all the beta emitters in the sample. Possible contributors to gross beta activity include strontium-89,90, radium-228, cesium-134, 137, lead-210, plutonium-241, and potassium-40. Tritium is mostly lost from the sample in the drying process, and some samples that require strong heating in preparation for counting may also lose much of the cesium-134, 137 by volatilization. Because beta particles are more penetrating than alpha particles, underestimating the gross beta activity because of sample attenuation is less of a problem than with gross alpha measurements. However, overestimation of gross beta activity because of high sediment levels is of similar concern as with gross alpha measurements.

Gross beta activity measured in surface waters can generally be accounted for by the naturally occurring isotopes of uranium, radium, potassium present in the surface waters. In other words, anthropogenic beta activity generally does not make a significant contribution to total gross beta measurements, and can generally be attributed to fallout from nuclear weapons testing.

At RFETS, it was found that there is enough naturally occurring uranium and potassium present in the surface water to more than account for the measured gross beta activity. Anthropogenic

TABLE 1
AVERAGE PERCENT CONTRIBUTION
TO GROSS ALPHA COUNT
IN RFETS POND WATER

Location	Radium	Thorium	Uranium	Plutonium	Americium
Pond B5	43	0.31	56	0.43	0.05
Pond A4	56	0.10	44	0.05	0.03
Pond C2	55	0.04	45	0.43	0.14

Reference: LANL 1993.

901-004V60cb\Table-1

beta activity from RFETS operations did not appear to contribute significantly to total beta activity levels detected in water samples (LANL 1993). Cesium-137 levels were consistent with that expected from global fallout, and potassium 40 levels were consistent with other Colorado waters (LANL 1993).

2.3 ANALYTICAL LIMITATIONS

The ability to detect radionuclides at environmental concentrations depends on the specific analytical method and instrument used and the length of time the sample is counted. Analytical limitations associated with radionuclides are described in terms of Minimum Detectable Activity (MDA), and Practical Quantitation Level (PQL). MDA is similar in concept to Method Detection Limit (MDL) used for other, non radioactive chemicals with the exception that counting times for radionuclides can be expanded to days or even weeks in order to detect very small values. However, these extremely long counting times are generally unrealistic for compliance monitoring.

In the Statement of Work for *General Radiochemistry and Routine Analytical Services Protocol (GRRASP)*, EG&G Rocky Flats, Environmental Management Department Version 2.1, 1991, page 19, MDA is defined as follows: "The smallest amount of sample activity using a given measurement process (i.e., chemical procedure and detector) that will yield a net count for which there is confidence at a pre-determined level that activity is present." At Rocky Flats, the MDA is calculated by the method of Currie, adapted and promulgated by the American National Standards Institute (ANSI N13.30, (draft) 1989, Health Physics Society Subcommittee WG 2-5, *Performance Criteria for Radiobioassay*). With this standard, MDAs depend on the standard deviation of appropriate analytical blanks, as opposed to only the corresponding variability of counting instrument background.

When using contract laboratories, RFETS currently specifies a Required Detection Limit (RDL) and expects contract laboratories to operate their equipment so that their MDAs meet the RDLs for each type of sample (EG&G 1991). Table 2 shows RFETS RDL values for water samples.

PQLs are defined by EPA as the level at which a contaminant can be ascertained with specific methods on a routine basis by well managed laboratories, and within specified precision and accuracy limits (56 FR 46906). PQLs are therefore higher than MDAs. PQLs are determined

TABLE 2
PRACTICAL QUANTITATION LIMITS FOR RADIONUCLIDES

Contaminant	Rocky Flats	EPA	CDPHE Workshop
	Water Sample RDL* (pCi/L)	PQL (pCi/L)	Recommended PQL (pCi/L)
Radium 226	0.5	5	5
Radium 228	1	5	5
Radon 222		300	300
Gross Alpha emitters	2	15	15
Gross Beta emitters	4	30	30
Uranium - natural		4	5
Uranium - 233+ 234	0.6		2
Uranium 235	0.6		2
Uranium 238	0.6		2
Thorium 230	1		2
Thorium 232	1		2
Total radiostrontium	1		
Strontium 89		5	5
Tritium	400	1200	1200
Americium - 241	0.01		0.2
Plutonium - 238			0.2
Plutonium - 239 + 240	0.01		0.2
Lead - 210			10
Total radiocesium	1		
Cesium - 134 (by gamma)	1		
Cesium - 137 (by gamma)	1		
Curium - 244	1		
Neptunium - 237	1		

*General Radiochemistry and Routine Analytical Services Protocol (GRRASP), Part B, Statement of Work, EG&G Rocky Flats, Version 2.1, 1991.

through evaluation of the results of interlaboratory studies, such as Performance Evaluation studies. In the absence of PE studies, PQLs are traditionally established at concentrations 5 to 10 times the MDL (or MDA).

Using data from a formal Performance Evaluation, EPA has established PQLs for most radionuclides of wide spread interest based on 100 minute counting times, plus or minus 20 to 50 percent acceptance limits, and at concentrations where it was estimated that 75 percent of all reporting laboratories will be within the specified acceptance range. Table 2 shows EPA established PQLs for various radionuclides.

In January 1992 the Radiation Control Division of CDPHE conducted an Analytical Radiochemistry Workshop on PQLs. The goal of this Workshop was to determine recommended PQLs for isotopes for which EPA had not published proposed PQLs in the Proposed Rule. Workshop participants included 11 laboratory experts knowledgeable in the day to day operations of analytical laboratories. Recommended PQLs were set at 5 times the highest detection limit reported by the eleven participating laboratories (i.e., 3 standard deviations), with the exception that detection limits deemed by the panel to be too high or too low were rejected from the analysis. Table 2 shows PQLs recommended by the Colorado Department of Public Health and Environment (CDPHE) Workshop.

It should be noted that numerous reviewers of the PQL Workshop final report, including some of the participants, had serious reservations regarding the methodology used by the Workshop to determine the recommended PQL list. The number of participating laboratories was far less than the number typically employed by EPA in a formal Performance Evaluation, did not include any laboratories outside the state of Colorado, did not employ any statistical methods to the PQLs reported by the laboratories, and did not calculate any Acceptance Limits to the recommended PQLs. In the Workshops defense, the Workshop was organized as an expert panel discussion rather than a quantitative Performance Evaluation, and did recognize its own limitations.

2.4 REGULATORY REQUIREMENTS/LIMITATIONS

Requirements pertaining to allowable levels of radionuclides in public water supplies or dischargeable to surface water or groundwater are incorporated into regulations and guidance documents published by both federal and state agencies. A comparison of various standards and regulated parameters is given in Table 3. At the federal level, allowable radioactive constituents and concentrations take the form of primary drinking water standards of general applicability

TABLE 3
STATE AND FEDERAL WATER QUALITY STANDARDS FOR RADIONUCLIDES

Radionuclide	Current SDWA MCL (pCi/L)	Proposed SDWA MCL (pCi/L)	CDPHE Statewide Standard (pCi/L)	RFETS Site Specific (pCi/L)	DOE DCG (pCi/L)	NRC Discharge Criteria (pCi/L)
Americium 241				0.05	30	20
Plutonium 239 + 240				0.05	30	20
Radon		300				
Radium 226		20				
Radium 228		20				
Radium 226 + 228	5		5			
Uranium 233 + 234, 238		30		5/10**	600	300
Tritium			20,000	500	2,000,000	
Strontium 89						8,000
Strontium 90			8			
Cesium 134			80			
Cesium 137						1,000
Cobalt 58						20,000
Cobalt 60						3,000
Thorium 230, 232			60			
Gross Alpha	15	15		7/11**	-	-
Gross Beta	4 mrem/yr	4 mrem/yr		5/19**	-	-

** First number is for Woman Creek, second number is for Walnut Creek

under the Safe Drinking Water Act (SDWA) (40 CFR 141, 142), or take the form of point source effluent limitations in a NPDES permit under the authority of the Clean Water Act (CWA) (40 CFR 122). U.S. Nuclear Regulatory Commission (NRC) guidance on the control of radionuclides in water discharged from nuclear power plants is found in 10 CFR 20, Appendix B. Guidance for discharge of radionuclides from nuclear weapons facilities is given in Department of Energy (DOE) Order 5400.5, "Radiation Protection for the Public and the Environment." In Colorado, the state regulates radionuclides as well as other water quality parameters through the adoption of statewide ambient water quality standards of general applicability, and by assigning stream standards and classified uses to individual water bodies. The state can also assign site specific water quality standards if the WQCC believes sufficient justification exists to do so.

For the most part, radionuclide concentration levels specified by the various administrative and regulatory agencies are based on presumed health risks to humans. SDWA maximum contaminant levels (MCLs) are established by EPA based on conservative assumptions of dose versus effect resulting in calculated "acceptable" lifetime mortality risks and/or lifetime cancer incident risks of between 10^{-4} (1 in 10,000) and 10^{-6} (1 in 1 million). Similar in approach, but slightly different in application, both DOE and NRC set concentration levels based on presumed "safe" exposure levels, rather than directly on specific risk calculations. For example, DOE established public dose limits (PDLs) for all sources of radiation discharged from DOE facilities, and developed a limited number of health based isotope specific derived concentration guides (DCGs) that represent maximum allowable concentration levels necessary to limit public exposure to an ingested 50-year effective dose of 100 millirem per year. NRC guidance limits radioactivity levels in water discharges from nuclear power plants to similar effective dose restrictions, and also provides a complete table of allowable discharge concentrations (in pCi/L) equivalent to the 100 millirem per year dose limit.

Federal drinking water quality standards currently exist for combined radium (226 and 228), gross alpha, and gross beta only, however, proposed changes to current SDWA standards for radionuclides were published by EPA in 1991 (56 FR 33050). As shown in Table 3, proposed changes to primary drinking water regulations would revise allowable radium concentrations, add new MCLs for uranium and radon, and establish maximum contaminant level goals (MCLGs) for regulated constituents. MCLGs reflect desired but currently unachievable water quality or conservative, protective water quality goals that reflect a lack of reliable health effects information. All radionuclides are classified as carcinogens by EPA, thus MCLGs for all radionuclides (as for all carcinogens) are zero.

CWA Ambient Water Quality Criteria (AWQC), which are designed to protect aquatic life and general (non-drinking) uses, do not specify concentration levels for any of the naturally occurring or man made radionuclides. As a result, effluent limitations incorporated into federal NPDES permits, which are generally based on AWQC, also do not generally include radionuclides. However, federal NPDES permits can adopt state water quality criteria as effluent limitation, as is the case at RFETS.

The SDWA also requires EPA to identify the Best Available Technology (BAT) for meeting the established MCL for each contaminant. To determine BATs, EPA takes cost into consideration and examine the actual performance of technologies under field conditions. As a consequence, BAT may change over time as emerging technologies are tested, proven, and become commercially available.

Table 4 lists current and proposed MCLs, and corresponding BATs for radionuclides regulated under the SDWA. Transuranic elements (e.g., americium, plutonium) and man made fission products (e.g., cesium, strontium) are not specifically regulated but do fall under the general category of alpha or beta emitters for which MCLs and BAT apply.

BAT and effluent limitations for other applications such as nuclear power plant discharges, uranium mining and milling operations, and environmental cleanup have not been regulatorily specified by EPA. This is because for uranium and the transuranium elements, pursuant to a Supreme Court ruling in Train v. Colorado Public Interest Research Group 426 U.S. 1 (1976), EPA lacks the authority under the CWA to regulate these radionuclides since they are "source" materials as defined by the NRC under the Atomic Energy Act. In most cases, however, drinking water plant BATs have been adopted as the technologies of choice for other applications, although significant research on alternative technologies continues.

Colorado has adopted statewide standards for most of the naturally occurring and man made radionuclides. Notably lacking from the statewide standards are the transuranic elements of plutonium and americium, and statewide standards for gross alpha and gross beta. Given the limited number of facilities managing transuranic materials, the WQCC decided to adopt site specific standards for these constituents applicable to stream segments at and below RFETS in 1992. In the absence of reliable health risk information, standards for uranium, plutonium, and americium were established at presumed ambient levels based on measurement protocols being used at the time (Table 3). As an additional protective measure, the WQCC also adopted

TABLE 4
EPA DRINKING WATER STANDARDS AND BEST AVAILABLE TECHNOLOGY
FOR REGULATED RADIONUCLIDES

Contaminant	Standards			Best Available Technology		
	Status	MCLG	MCL	Conventional Processes	Specialized Processes	
Beta-Particle and Photon Emitters	Final Proposed	zero zero	4 mrem/yr ¹ 4 mrem/yr ¹	Coagulation/Filtration Coagulation/Filtration	Ion Exchange, Reverse Osmosis	
Alpha Emitters	Final Proposed	zero zero	15 pCi/L 15 pCi/L	Coagulation/Filtration Coagulation/Filtration	Reverse Osmosis	
Radium-226 + 228	Final	zero	5 pCi/L	Coagulation/Filtration	Ion Exchange, Reverse Osmosis	
Radium-226	Proposed	zero	20 pCi/L	Lime Softening	Ion Exchange, Reverse Osmosis	
Radium-228	Proposed	zero	20 pCi/L	Lime Softening	Ion Exchange, Reverse Osmosis	
Radon	Proposed	zero	300 pCi/L		Aeration	
Uranium-233, -234, -238	Proposed	zero	20 µg/L ²	Coagulation/Filtration, Lime Softening	Anion Exchange, Lime Softening	

¹4 millirem/yr effective dose equivalent for 10⁻⁴ lifetime incident risk.

²20 µg/L uranium equals approximately 30 pCi/L.

standards for tritium, general gross alpha and gross beta below current or proposed federal standards.

Stream standards (either statewide or site-specific) are generally used as the basis for establishing enforceable effluent limitations under a state issued discharge permit. These state standards can also be used as treatment goals for federally sponsored remedial actions under CERCLA or for state sponsored remedial actions under corresponding state laws. Since surface water management at RFETS is or will be covered by a discharge permit or by CERCLA, radionuclide standards can be enforced, and treatment capabilities to achieve these standards must be investigated and implemented if possible.

2.5 **CURRENT WATER QUALITY AND POTENTIAL TREATMENT NEEDS**

Based on summary statistics from various water quality monitoring conducted at RFETS, all of the radionuclide parameters of particular concern (e.g., americium, plutonium, uranium, gross alpha, and gross beta) have the potential to exceed WQCC standards (LANL 1993; DOE 1994b). Uranium, gross alpha, and gross beta also have the potential to exceed SDWA MCLs.

Table 5 lists maximum observed concentrations since 1991 for various radionuclides, and estimates maximum concentrations for treatment. Maximum concentrations for potential treatment were conservatively estimated at three times maximum observed concentrations from the two data sources cited. The factor of three multiplier was arbitrarily selected based on a review of the summary statistics which showed maximum observed concentrations were 1.5 to 5 times reported mean values. Applying a similar factor to maximum observed values provides a high degree of confidence that estimated maximum concentrations will not be exceeded.

The removal efficiencies required to achieve standards varies with the parameter of interest, and the particular standard chosen for comparison. Table 5 also calculates required removal efficiencies to meet either SDWA or WQCC standards. In all cases, meeting site-specific WQCC standards requires higher removal efficiencies than meeting SDWA standards.

2.6 **GENERAL UNIT PROCESS DESCRIPTIONS**

Since radioactivity occurs at the nuclear level and is generally independent of the chemical form of the element, all treatment approaches for radionuclides are based on separation methods that take advantage of differences in physical or chemical properties of different isotopes to isolate

TABLE 5
ASSUMED MAXIMUM CONCENTRATIONS AND
REQUIRED REMOVAL EFFICIENCIES
TO ACHIEVE WQCC AND SDWA STANDARDS⁶

Radionuclide	Maximum Observed Pondwater or Stormwater Concentration (1991-1994) (pCi/L) ¹	Maximum Observed Concentration from LANL Characterization Study ² (pCi/L)	Assumed Maximum Concentration for Treatment (pCi/L) ³	Removal Efficiency Percent Required to Meet:	
				WQCC Site-Specific or Statewide Standard	SDWA MCL or Proposed MCL
Americium-241	0.45	1.03	3.09	98.4	In Compliance ⁴
Gross Alpha	25	14.1	75	91	80
Gross Beta	59.2	20.1	207.6	97.6	90.5 ⁵
Plutonium-239 + 240	0.58	3.09	9.27	99.5	In Compliance ⁴
Radium-226	0.47	8.8	26.4	81	24.3
Radium-228	2.7		8.1	38.3	In Compliance
Radium-226 + 228	3.17		9.51	47.4	47.4
Strontium-89 + 90	2.05		6.15	In Compliance	In Compliance
Thorium-230 + 232	0.91	0.679	2.73	In Compliance	In Compliance
Tritium	1200		3600	86.1	
Uranium-233 + 234	55	7.59	165	97	81.8
Uranium-238	6.929	7.96	23.9	79.1	In Compliance

¹Highest observed concentration from regularly scheduled pondwater or stormwater sampling. Data taken from Tables 4-5, 4-12, or 4-18, *Final Draft, Pond Water Management IM/IRA Decision Document* (DOE 1994b).

²Highest observed concentration from Tables II, III, or VIII, *Characterization of the Radioactivity in Surface Waters and Sediments Collected at the Rocky Flats Facility* (LANL 1993).

³Maximum concentration is the higher of 3 times Column 1 or 3 times Column 2.

⁴Conservatively based on 15 pCi/L gross alpha standard since no MCL exists for americium or plutonium.

⁵Conservatively based on 20 pCi/L radium-228 standard.

⁶See Table 15 for comparison of required removal efficiencies to removal efficiencies achievable by Best Available Technology.

the radioactive atoms from the non-radioactive atoms. In general, all the treatment technologies for removal of low-levels of radionuclides from water can be grouped into two classes: physical treatment/separation technologies and chemical treatment/separation technologies. Biological processes are a special class of physical treatment due to the influence of metabolic processes.

All the separation methods try to associate the radioactive atoms with a solid phase, either by precipitation or adsorption. The radioactive solid phase is then removed from the water stream by sedimentation and/or filtration, or retention on a packed column.

The majority of conventional treatment technologies for suspended particle removal, and removal of dissolved metal and inorganic constituents also remove radionuclides (Cothorn and Rebers 1990; EPA 1991). The ability of these technologies to remove particular isotopes is a function of how these elements occur in a natural water system, and a knowledge of the aqueous chemistry of these constituents. The following text gives a brief description of current water treatment processes, their current application in removal of radionuclides, and some of the limitations associated with each process.

Forced Evaporation

Evaporation processes are applicable to non-volatile (e.g., solid phase) radionuclides of any size, but are ineffective for gaseous or aqueous phase radionuclides such as radon and tritium because these constituents remain in the condensate after treatment. An aqueous waste stream is heated to drive off free water as vapor and produces a radionuclide free product water when the vapor is condensed in a succeeding step. Equipment requirements and power costs generally make this technology uneconomical for treatment of dilute waste streams when compared with other technologies. Evaporation processes are generally used for dewatering concentrated brines, sludges, or other waste streams from other unit processes such as reverse osmosis and sedimentation rather than as a primary treatment process.

Oxidation/Reduction

Oxidation/reduction processes are applicable to ionic radionuclides which commonly occur in several oxidation states, such as uranium, plutonium, and americium. Oxidation and reduction reactions are used in adsorption, coagulation, or chemical precipitation processes to change the oxidation state of a radionuclide in order to alter its solubility and separability. For example, the oxidation state of uranium can be chemically changed from +4 to +6 by addition of a strong

oxidant, making it less soluble and enhancing a precipitation process. Oxidation/reduction processes must be followed by pH adjustment, precipitation, and suspended solids removal steps, and produces radioactive sludge that requires dewatering, and/or solidification prior to disposal.

Chemical Precipitation

Chemical precipitation processes are applicable to dissolved ionic radionuclides which form insoluble compounds when other chemicals are added to the water. The chemical composition of a solution is adjusted so that component ion concentrations exceed their solubility product, forcing the ions out of solution. This process generally involves either raising the pH through lime softening, or by adding precipitating agents such as sulfides and can often be tailored to specific contaminants. Dissolved metals and radionuclides may be precipitated from aqueous solutions as hydroxides, sulfides, and carbonates. Hydroxide precipitation using lime is most common. Caustic soda, alum, ferric sulfate, and ferrous sulfide also are used. Although not all metals exhibit minimum solubility within the same pH range, a pH between 9 and 11 is commonly used to precipitate metals. For uranium removal, the critical pH appears to be near 10.6. Precipitation processes must always be followed by suspended solids removal (i.e., settling and/or filtration), and always generates a sludge requiring further treatment or disposal.

Clarification/Sedimentation

A clarification/sedimentation process is used in conjunction with precipitation or coagulation processes to remove agglomerated and settleable solids. This process is effective at removing coarse fraction radionuclides that physically, chemically or electrically bond to flocculants, coagulants, and/or colloidal and suspended materials. Clarifiers/sedimentation basins are standard equipment in virtually all wastewater treatment plants. Most clarifiers combine chemical/flocculent addition, mixing, and settling into a single basin or tank, which is then followed by filtration steps. Clarification/sedimentation processes operate on the principles of contact time (for mixing) and detention time (for settling) to increase average particle size and physically settle out heavy and coarse fraction components by gravity. Cyclones are sometimes used to speed up the settling process. This process is generally used as a pretreatment step to more advanced technologies and always produces a wet sludge requiring further treatment.

Primary Media Filtration

Media filtration removes radionuclides attached to suspended particles by physically trapping these particles in the pore spaces of a bulk granular material. Nominal removal down to approximately 1.0 micron size range is possible although most media filters are nominally rated in the 20 to 50 micron range. Filters may be a single media such as sand, or multiple layers of different media such as sand, anthracite coal, garnet, or other granular material. Media filters are very versatile, can operate as pressurized or unpressurized units, at fast or slow throughput rates, and in upflow or downflow configurations.

Microfiltration/Ultrafiltration

Removes radionuclides attached to suspended or colloidal particles below the 0.45 micron size range. Particulate filtration efficiencies are achieved by using tightly woven filter fabrics of various construction (bags, cartridges, etc.). Nominal filtration of colloidal particles down to .05 microns has been claimed, however these claims have not been verified. Absolute filtration effectiveness has been demonstrated by Pall Corporation down to approximately 0.2 microns (Ultipor GF®). These processes are subject to frequent plugging and breakthrough if not adequately protected by pre-filters or other processes. Bags and cartridge filters are at present a non recyclable solid waste form and are dried and then packaged and disposed of as low level radioactive waste.

Filter ratings are given on either an absolute or a nominal basis. Nominal ratings are generally the largest pore size of the filter. A nominal rating is frequently based on weight removal of a percentage of particles at a given size and larger, such as 99 percent removal of particles 20 microns or greater. However, such a rating does not give a good indication of the ability of the filter to remove particles as a function of size, since particles of a larger size than the nominal rating can and do pass through the mesh. An absolute rating provides the clearest indication of filter efficiency. An absolute sizing is a direct measurement of *beta ratios* as a function of particle diameter. *Beta ratio* is defined as influent particle count divided by effluent particle count for a particular particle size range. The Pall Corporation pioneered this type of testing of filters, and remains a leader in submicron filter technology.

Filter systems feature different styles of equipment including cartridge filters, basket assemblies with disposable cartridges, disposable baskets, and in-to-out flow mono cartridge systems. Filter media for these systems ranges from string-wound and wound blanket/matrix media, to pleated

cellulose media, to glass and nylon fiber media. Thinner glass micro fibers (2 um size) allow up to 50 percent additional area to be pleated into a filter cartridge than conventional cellulose fibers. Currently, glass fiber and nylon fiber media that feature a positive *zeta potential* (the effective electric charge on a particle that attracts a diffuse layer of other charged species) have the greatest removal efficiency at the lowest absolute size rating. Since many fine particles in aqueous systems, including radionuclides, possess a net negative surface potential, the positive zeta potential on the fibers improves removal by electrostatic adsorption of negative particles even smaller than the absolute size rating of the filter (Weber et al. 1989).

Adsorption

Adsorption processes work by binding contaminants such as radionuclides to high surface area materials (sorption media) such as granulated activated carbon, activated alumina, and ferrite. Physically, adsorption processes generally occur by passing a water stream through a tank containing the sorption media, thus sorption media also provide some filtration capacity.

There are three mechanisms of adsorption processes, all of which use a surface attraction phenomenon in which molecules in solution are attracted to the surface of a solid through attractive electrical forces. *Physical adsorption* results from the action of Van Der Waals forces, relatively weak electrical interactions produced by the motion of electrons in their orbitals. *Chemical adsorption, or chemisorption*, involves electron interactions between specific surface sites and solute molecules, resulting in the formation of a bond that can have all of the characteristics of a "true chemical bond." Chemisorption is typified by a much stronger adsorption energy than physical adsorption. *Electrostatic adsorption* is the Coulombic attractive force between ions and charged functional groups, and is synonymous with the term ion-exchange.

Adsorption depends on the strength of the molecular attraction between the adsorbent and the contaminant, the type and characteristics of the adsorbent, the pH and temperature of the solution, and the surface area of the adsorbent. The surface area of an adsorbent is greatly increased by its porous structure. Generally, adsorbents with a large number of smaller pores have greater surface area and more sites for adsorption to occur. Large molecules tend to be adsorbed more strongly than small molecules, and less soluble compounds are more readily removed by the process than the more soluble compounds. Adsorption continues until an equilibrium is established between the concentration of contaminant in solution and the concentration on the

solid adsorbent. This equilibrium is frequently expressed on a mass of contaminant to mass of adsorbent basis.

Since sorption processes are reversible, sorption media are generally chemically regenerated which results in a concentrated side stream requiring further treatment. For radionuclide applications, sorption media are generally solidified and disposed of as low level waste.

Ion Exchange

Ion exchange processes selectively remove soluble ionic contaminants by replacing them in solution with other ions, such as sodium or chloride. Ion exchange has been successfully used to remove radium and uranium and to treat a wide variety of metal cations and anions. The resins can be highly selective. The process is not applicable to wastes containing high solids or high contaminant concentrations. Ion exchange resin is chemically regenerated or replaced with new, thus, there is always a residual waste that must be treated or disposed of. Sequential ion exchange that replaces cations with hydrogen and anions with hydroxide yields water with no added salts or acidity.

Physically, an ion exchange system generally consists of a column packed with an ion exchange material. The ion exchange material is commonly a synthetic resin in bead form, although in some cases naturally occurring aluminum silicate clays or zeolites are used. These resin are manufactured with the replaceable (and more acceptable) ions weakly bound to the surface of the resin beads by electrostatic forces. The solution containing the unwanted ions is fed through the column and as the liquid contacts the resin, the undesirable ions in the solution are exchanged for the ions on the resin. Ion exchange resins for cation removal can be strongly to weakly acidic and can be in either the hydrogen or sodium forms. Resins for anion removal are available in strongly to weakly basic forms and are usually in either the hydroxide, the chloride, or the bicarbonate form. If a solution contains both undesirable cations, and undesirable anions, two different types of resins are used. These can either be placed in one column or they can be placed in separate columns in series.

Ion exchange is a very versatile and effective tool for the treatment of aqueous hazardous wastes, because it has the ability to purify, as well as concentrate pollutants. It is best suited for the selective detoxification of large volumes of wastewater containing relatively low levels of contaminants. Since the offending pollutant is often present in low concentrations, ion exchange is frequently more efficient in treating large flows of dilute hazardous waste streams than many

other processes. Operating costs depend mainly on the amount of the pollutant to be removed since the major operating costs (resins replacement and regeneration costs) are a function of the absorptive capacity of the resin rather than on flow rate. Hydraulic flow rates only affect capital costs.

Several equipment designs are currently employed, ranging from fairly simple and inexpensive units similar to the domestic water softener to large, continuous moving-bed plants. The process is usually carried out cyclically, alternating between service and regeneration modes, and can be either manually or automatically controlled. As with adsorption media, ion exchange resins for radionuclide removal are generally solidified and disposed of as low level waste once their useful life has expired.

Membrane Separation

Membrane separation technologies include ultrafiltration and reverse osmosis, which is sometimes called *hyperfiltration*. These technologies use pressure and a semipermeable membrane to physically separate nonionic materials from an aqueous solution. Membrane separation techniques may be used with most dissolved or colloidal suspended radionuclides. In ultrafiltration and hyperfiltration systems, the membrane retains materials based solely on size, shape, and molecule flexibility. As a feed solution is pumped through a membrane module, the membrane acts as a sieve to retain dissolved and suspended materials that are physically too large to pass through its pores. The retentate then exits the module separately from purified water as a highly concentrated brine containing dissolved salts, as well as the target contaminants. This brine requires additional treatment prior to disposal. This technology has been very successful at radionuclide removal if water is properly pretreated to prevent membrane plugging or deterioration due to scale formation, biological growth, or chemical attack.

Two common membrane materials are polysulfone and cellulose acetate. Polysulfone is the most versatile because it can tolerate temperatures between 0 and 70°C and pH from less than 1 to 13. It also can be cleaned with a wide array of cleaning agents. Cellulose acetate is also a popular membrane material; however, it can only be used at a pH 2.5-7 and temperatures from 0 to 50°C. Types of ultrafiltration and hyperfiltration membrane configurations include tubular, spiral wound, hollow fiber, and plate and frame.

The major difference between ultrafiltration and hyperfiltration is that hyperfiltration (e.g., reverse osmosis) typically removes species having a molecular weight of 100 to 500; ultrafiltration

removes species having a molecular weight greater than 500. The two membrane separation methods use identical operating principles. The retention capability of ultrafiltration and hyperfiltration membranes is characterized by the molecular weight cutoff. Ultrafiltration membranes are available that retain molecular weights ranging from 500 to 1,000,000. However, since there is no uniform method of measuring the molecular weight (MW) cutoff of membranes, MW cutoffs specified by different manufacturers are not necessarily comparable. Although membrane separation is still an expensive treatment process, its increased use in recent years has brought costs down to comparable levels with other treatments like ion exchange.

Biosorption

Biosorption is a metabolic-driven process that binds metals, ions, or radionuclides to a biomass (Gadd 1990). Biosorption includes the adsorption and absorption (the chemical and physical reactions that occur) and the associated metabolism-independent processes.

Many microorganisms have the capacity to accumulate metallic cations from the environment, via a process generally referred to as biosorption. Cation accumulation by microbial cells is a complex process where the degree of concentration inside the cell (absorption) or on the cell surface (adsorption) is dependent upon the cationic species, the properties of the cell (cellular charge, metal tolerance, competition for active binding sites), and environmental factors such as pH, temperature, and interference from other chemicals in solution (Barratt 1990).

Both living and dead bacteria, fungal and yeast, and algae biomass can adsorb metal ions. However, the uptake capacity of dead cells may be greater, the same, or less than the capacity of the living cells. The killing treatment used and any alterations in the wall structure determine the capacity for metal uptake (Duddridge and Wainwright 1980 in Gadd 1990). The adsorption capacity of dead fungal biomass can be the same or even much greater than that of ion-exchange resins (Tsezos and Keller 1983 in Gadd 1990). A more detailed discussion of various biosorption processes is given in Section 4.5.

Wetlands Treatment

In a wetland system, a variety of processes interact to remove metallic contaminants, all of which have potential application to radionuclides. The following processes are the principal metal removal processes of a passive mine drainage treatment system (Cohen and Staub 1992): (1) adsorption and complexation of metals by organic substrates; (2) microbial sulfate reduction

followed by precipitation of metals as sulfides; (3) precipitation of ferric and manganese oxides; (4) adsorption of metals by ferric hydroxides; (5) metal uptake by plants; and (6) filtration of suspended and colloidal materials. Limited studies of constructed wetlands for treatment of acid mine drainage have shown maximum removal rates for iron, zinc, lead, copper, and cadmium were 97 to 100 percent (Cohen and Staub 1992). It is known that all of the processes listed above will remove radionuclides, however, no data on maximum removal rates for radionuclides in a wetland system were found.

CHAPTER 3

TECHNOLOGY ASSESSMENT CRITERIA AND SELECTION METHODOLOGY

In this chapter a process is outlined for making a preliminary selection of low level radionuclide removal technologies for water treatment at RFETS. The approach is consistent with EPA methodology (EPA 1988, EPA 1990) and is similar to the one described in the RFETS *Final Treatability Studies Plan* (DOE 1991b). The main difference is that in this report, technologies are evaluated for their suitability to be a part of an overall water treatment scheme, whereas in the *Final Treatability Studies Plan*, technologies were selected for both soil and water treatment, and technologies whose primary value pertained to pretreatment or residuals management were rejected.

Each removal technology, for which performance data was found, was initially evaluated as suitable or not suitable according to four screening criteria. A single "not suitable" judgement against the listed screening criteria caused rejection of that technology from consideration for short term implementation. Technologies that passed the initial screening process were then subjected to a comparative analysis of costs, ease of implementation, and adverse impacts (such as waste generation) in order to come up with final technology selections. Figure 1 is a flow chart showing how the screening and selection process was conducted.

The following sections describe the screening criteria and comparative evaluation measures used in the selection process. Assessment results and other conclusions are given in later chapters.

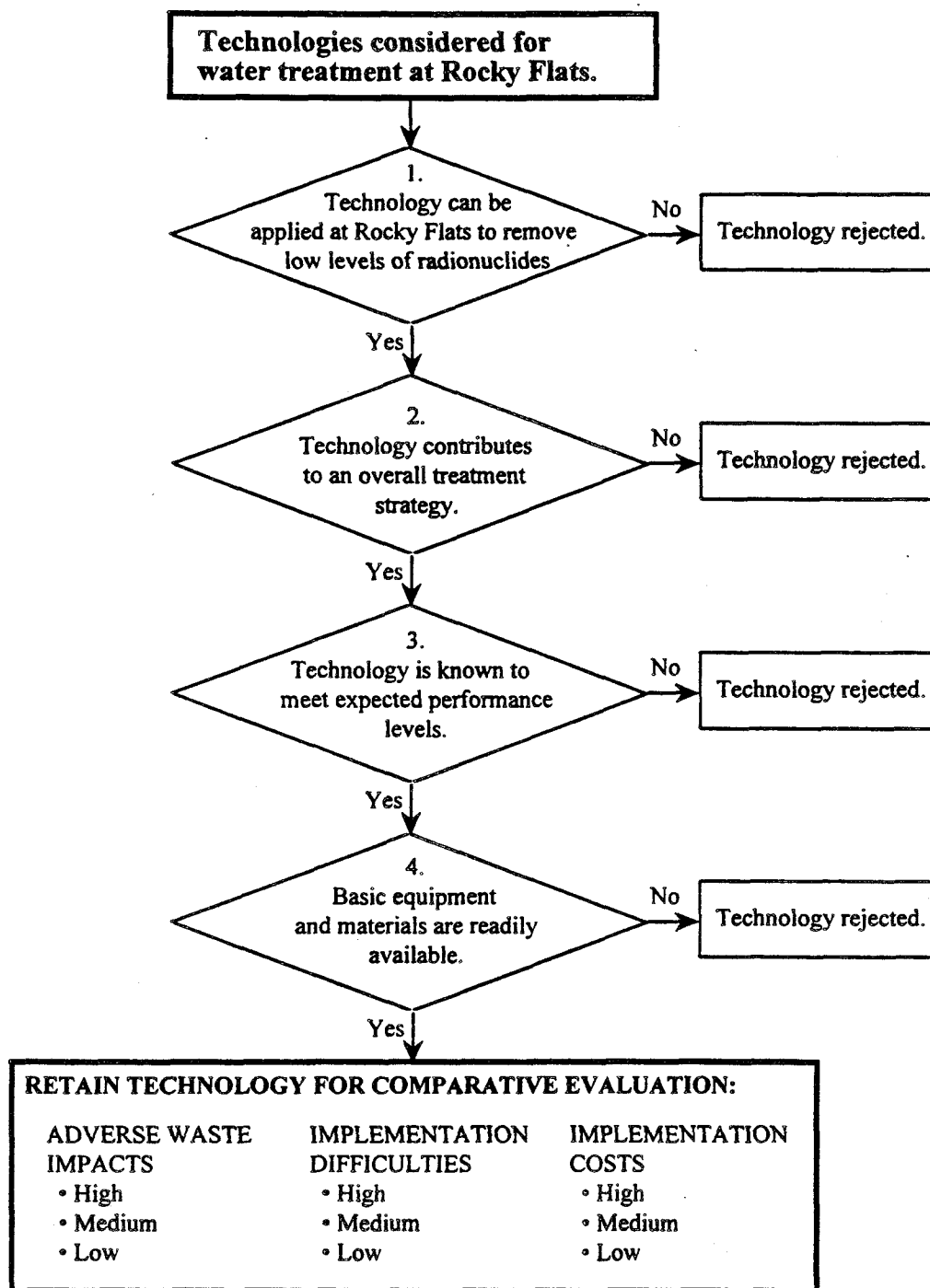
3.1 SCREENING CRITERIA

Four initial screening criteria were used to determine the suitability of individual technologies for current implementation. These criteria are described below.

1. Applicability: Does the technology in question address the parameters of interest to RFETS?

Most all conventional/emerging physical and chemical treatment technologies pass this screen. Separation and removal techniques specific to removal of organic chemicals or which target gaseous or liquid phase contaminants are generally not applicable.

FIGURE 1
FLOW CHART - SCREENING AND SELECTION PROCESS



2. Contribution to an overall removal scheme: Can the technology fit into an overall removal strategy of pre-treatment, main-treatment, or post-treatment so that it contributes significantly to the overall net removal efficiency?

Individual technologies need not provide single step removal of contaminants to the levels required by imposed standards. However, each technology that passes this screen must provide a level of removal consistent with overall removal goals or remove other parameters such as suspended solids which interfere with subsequent radionuclide removal.

3. Technological maturity: Is the current state of the technology well enough developed to warrant confidence in an expected level of performance?

Most emerging technologies are not well enough developed to pass this screen. To pass this screen, a technology must have, for the parameter of interest, a minimum of pilot scale performance data.

4. Availability: Is the required basic equipment readily available, and is there a reliable source of replacement parts, chemicals or other necessary components?

In general, most all technologies use conventional equipment such as tanks and pumps. This criteria evaluates the availability of specialized flocculants, resins or filtration membranes.

3.2 COMPARATIVE EVALUATION MEASURES

For the technologies passing the initial screening criteria, three comparative evaluation measures were used to select technologies for potential implementation. These evaluation measures are described below. Where possible, these evaluation measures looked at actual costs, or attempted to reasonably quantify the other factors considered, however, since definitive information was generally unavailable at the conceptual level at which the technologies were being evaluated, comparative evaluations are done using a high-medium-low ranking scheme.

1. Capital, operating and maintenance costs: Are costs, including capital costs, labor, power, chemical, and residuals management, likely to be high compared to the expected benefits?

Although this criterion is important, it was often difficult to apply because operating and maintenance (O&M) costs for unit processes were difficult to separate from system costs,

and, even where they were well established, were considered highly site specific. Thus, this criteria focuses more on capital costs than O&M costs, however, O&M costs were considered when good information was available. Since the frequency, flow rate, and volume of treatment is indeterminant, preference is given to low capital cost technologies.

2. Implementation difficulties: Are there special installation and/or construction problems? Does the technology require intensive labor support to function properly?

Technologies that require significant ancillary construction such as new buildings, special secondary containment or require a large land surface cannot be implemented quickly due to the engineering design and environmental impact documentation that must be completed. Similarly, technologies that require constant operator oversight to function at optimal efficiency are more likely to fail to meet expected performance goals.

3. Adverse waste impacts: Does the technology produce excessive toxic or hazardous by-products, residuals, sludges, or waste streams requiring substantial additional processing and/or treatment? Is an equivalent technology available that has a less adverse impact?

All technologies used to remove radionuclides from water will result in a waste stream that requires additional treatment or handling prior to disposal. For this criteria both the volume and form of the waste are important. Preference is given to technologies that limit total waste volume, and limit the creation of mixed (e.g., hazardous and radioactive) wastes, which are difficult and expensive to handle and dispose of using conventional secondary waste treatment processes and disposal methods.

CHAPTER 4

PERFORMANCE RESULTS OF RADIONUCLIDE REMOVAL TECHNOLOGIES

This chapter of the report documents the performance of current and emerging technologies used to remove radionuclides from water. Performance results are based on a combination of bench tests, pilot scale treatability studies, and full scale treatment plant operations. Removal efficiencies and corresponding influent and effluent concentrations for various specific studies or for "generic" treatability investigations are given in numerous tables throughout this chapter. Summary tables of performance data for operational water treatment systems (Table 17) and emerging unit processes (Table 18) are given at the end of this chapter. Interested readers are referred to the documented reference list for more detailed information.

4.1 SUMMARY

The vast majority of performance data on radionuclide removal is focused on naturally occurring radioactive materials (NORM) and emphasizes treatment for radium, radon, and uranium. Most of this data was generated by or for drinking water treatment plants, reflecting the fact that regulations exist for NORM concentrations in water supplied for public consumption. Thus, removal data for NORM is well documented. Additional performance data for the removal of uranium and radium has been generated by the uranium mining industry, generally as part of environmental (generally groundwater) remediation projects.

Performance data for the removal of low levels of radioactive fission products (e.g., strontium, cesium, etc.) from wastewater effluents has also been documented. The available data on these constituents generally comes from nuclear power plants, and to a lesser degree from facilities within the Department of Energy (DOE) nuclear weapons complex. There are also some good detailed reports on the Chernobyl and Three Mile Island accidents that address fission product removal, and to a lesser degree transuramic elements, however, influent and effluent activity levels considered in these reports were many orders of magnitude higher than the picocurie and subpicocurie activity levels of interest here.

Very little performance data exists for the removal of low levels of plutonium and americium from natural waters. The available data comes almost exclusively from DOE facilities, and none of the data for these constituents comes from full scale treatment facilities. Although a number of treatability studies have been completed, planned, or in progress, at present, no definitive

information exists on technologies for treating water for plutonium and americium to the 0.05 pCi/L level required by current state standards.

Current technologies are generally defined in terms of Best Available Technology (BAT). These technologies have proven effectiveness and are readily available. Current BAT's for radionuclides are defined regulatorily only for drinking water plants, and include ion exchange, lime softening, coagulation/filtration, and reverse osmosis. BAT's generally target radium and/or uranium for removal since these elements are the most common radioactive contaminants in natural waters. Lime softening and coagulation/filtration generally have lower capital costs since clarifiers and filters are common equipment used in the water and wastewater treatment industries, and removal of radionuclides can be achieved by process changes rather than equipment changes. Ion exchange and reverse osmosis, although more expensive and not as common as lime softening and coagulation/ filtration, are also well established technologies that are used in industrial and municipal settings.

Emerging technologies include both new technologies and improvements in existing technologies. NORM removal studies are generally directed at improvements in existing BAT. For example, new ion exchange resins have been tested, as have proprietary media filter designs and new types of flocculants for standard precipitation/clarification technologies. Emerging technologies for other radionuclides, particularly plutonium and americium, are new materials such as magnetic media or bone char, or are investigating the performance of conventional BAT since performance data for these constituents is currently lacking.

4.2 CURRENT TECHNOLOGIES AND APPLICATIONS

4.2.1 System and Unit Process Performance at Drinking Water Facilities

As discussed previously, drinking water plants for which radionuclides are determined to be a concern are required to install Best Available Technology (BAT), or better, for these contaminants. Most drinking water plants are generally not concerned with radionuclides, rarely monitor influent concentrations, and are able to achieve current SDWA standards with conventional coagulation/filtration treatment processes which remove other undesirable constituents at the same time. The few facilities that need to install special removal processes for radionuclides generally use ion exchange and reverse osmosis to achieve the higher rates of removal not possible using coagulation/filtration and lime softening. Ion exchange and reverse

osmosis treatment systems require substantial pretreatment of the influent to remove suspended solids in order to operate efficiently.

4.2.1.1. Full Scale Treatment Plants

The best source of information for documented studies specific to radionuclide removal efficiencies and effluent levels for full scale drinking water treatment plants are EPA documents. Other sources of performance information include summaries prepared by private researchers, performance studies conducted at the Denver Water Boards Potable Reuse Demonstration Plant in the mid-1980s, and removal studies performed at small scale point of use facilities.

EPA's proposed Radionuclides Rule (56 FR 33050 - National Primary Drinking Water Regulations; Radionuclides, July 18, 1991) summarizes removal capabilities and theoretical technology limits for the BATs identified by EPA for removal of the subject radionuclides. Tables 6 and 7 are reproduced from the Proposed Rule (56 FR 33083). These tables basically summarize performance data contained in other EPA Technology and Cost (T&C) documents, (EPA 1984, 1985, 1986a, 1986b, 1987a, 1987b, 1991a), and incorporate the results of a six-state survey on uranium removal which is described separately below.

In the late 1980s, EPA conducted an extensive project to document radionuclide removal efficiencies for water treatment plants. Specifically, EPA searched for "conventional water treatment facilities" with influent values for total uranium equal to or greater than 10 pCi/L in a six state region. In the study area, EPA identified 55 water treatment plants with total uranium inflow concentrations exceeding 10 pCi/L. Only 4 of the 55 plants provided treatment beyond typical sand filtration and chlorination.

The four treatment plants included those in Harrisburg, South Dakota (where no data were available), Denver, Colorado (available data did not enable an assessment of uranium removal efficiencies), North Table Mountain Water District in the western Denver suburbs (declined to participate in EPA evaluation), and the City of Arvada, Colorado. The only facility with reliable uranium removal data, the Arvada (Colorado) Water Treatment Plant, experienced a range of removal efficiencies for uranium of 18 to 90 percent.

TABLE 6
CONTAMINANT REMOVAL RATES

TABLE 5. BAT CONTAMINANT REMOVAL RATES ¹

Contaminant	Ion exchange	Lime softening	Aeration	Reverse osmosis	Coagulation/ filtration
Radon			Up to 99.9%		
Radium (226 and 228)	80-97%	75-85%		87-98%	
Uranium	65-99%	85-99%		98-99.4%	80-95%
Beta Emitters					
—Ce-137	95-99%			90-99%	
—I-131				90-99%	
—Sr-89	95-99%			90-99%	
—Mixed commercially produced radionuclides	* 90-99%			98-99%	

¹ Information regarding removal efficiencies, test conditions and other factors are contained in the EPA Technology and Cost documents (T&C) and cost supplements to each T&C, i.e., for uranium, radium, radon and manmade radionuclides (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988a).

* Mixed bed or two bed (anionic/cationic) exchange resins. Removal rate does not include I-131.

TABLE 7
TECHNOLOGY LIMITS FOR RADIONUCLIDE REMOVAL

**TABLE 6.—TECHNOLOGY LIMITS FOR
RADIONUCLIDE REMOVAL**

Contami- nant/ Technolo- gy (BAT)	Greatest percent removal	Maximum ¹ Influent (pCi/l)	Achievable effluent (pCi/l)
<i>Radon</i>			
Aeration	99.9	26,000	26
<i>Radium- 226</i>			
IE	97	15	0.45
LS	95	15	0.75
RO	98	15	0.30
<i>Radium- 228</i>			
IE	97	12	0.36
LS	95	12	0.60
RO	98	12	0.24
<i>Uranium</i>			
IE	99	88	0.9
LS	99	88	0.9
RO	99	88	0.9
CF	95	88	4.4
<i>Beta Emitters</i>			
Two bed ion ex- change	99	.	.
RO	99	.	.

¹ Maximum levels in groundwater sources of drink-
ing water as reported in NRS.

Note: IE (ion exchange); LS (lime softening); RO
(reverse osmosis); CF (coagulation/filtration).

Source: (EPA, 1984b; 1985b; 1986b; 1986c;
1987b 1987c; 1987d; 1988a).

Source of Table 6 and 7: National Primary Drinking Water Regulations; Radionuclides, Proposed Rule. Federal Register Vol. 56. 1991.

In short, EPA's comprehensive water treatment facility inventory in a six state region failed to produce reliable evidence regarding the extent to which water treatment facilities are presently lowering radionuclide levels.

EPA has generated limited additional information since publication of the Proposed Rule. More recent summaries of removal efficiencies, incorporating additional parameters and additional technologies, were completed by private researchers in 1992 (WWE 1992b) and 1993 (AWWA 1993). Tables 8 and 9 present these most recent removal summaries.

4.2.1.2 Denver Water Board, Potable Water Reuse Demonstration Project

A report entitled *Denver's Potable Water Reuse Demonstration Project--Phase II--Preliminary Process Evaluation* (Lauer 1988) was prepared by William C. Lauer of the Denver Water Department. The report described a large-scale advanced treatment facility (the Reuse Plant) which received secondary (e.g., treated) effluent from Metro Denver Water Reclamation Facility and reprocessed this wastewater to exceed drinking water standards. The Demonstration Project was designed to investigate the feasibility of reprocessing sanitary effluents for domestic supply, succeeded in doing so, and was mothballed in 1991. A schematic diagram of the facility is shown in Figure 2.

Although not a specific emphasis of the Demonstration Project, influent and effluent concentrations of regulated radioactive constituents were evaluated as part of the general scope of performance and health effects studies. The Reuse Plant employed three barriers to radioactive constituents: (1) high pH lime clarification; (2) granular activated carbon; and (3) reverse osmosis. A summary of performance results follows.

Average plant influent gross alpha count was 3.6 pCi/L and gross beta count was 6.5 pCi/L over a 2-year study period. Both these parameters were always below detection limits (not given) in the effluent, however, the removal efficiency of individual unit processes for gross alpha and gross beta was not calculated. Uranium influent concentrations averaged .008 mg/L (12 pCi/L) and ranged as high as .017 mg/L (27 pCi/L). Lime clarification showed an average uranium removal efficiency of 79.8 percent. For all radionuclides monitored, Reuse Plant effluent was below detection limits (not given). Other useful data in Lauer's report includes influent and effluent concentrations of a wide variety of organic and inorganic constituents, unit process descriptions, operating costs (1986) and design specifications.

TABLE 8
SUMMARY - BEST AVAILABLE TREATMENT TECHNOLOGIES
FOR RADIONUCLIDES

Radionuclide	Best Available Technologies (BATs)	U.S. EPA Reported Removal Rate	Removal Rate Based on Review of Actual Study Data ⁽¹⁾	Basis of Actual Study
Lead 210	Coagulation Lime Softening		Up to 97% ⁽⁴⁾ Up to 98% ⁽⁴⁾	Laboratory Study Laboratory Study
Radium 226	Ion Exchange Lime Softening Lime Softening Reverse Osmosis	80 - 97% ⁽²⁾ 75 - 95% ⁽²⁾ 87 - 98% ⁽²⁾	81 - 97% ⁽²⁾ 70 - 95% ⁽⁴⁾ 81 - 95% ⁽²⁾ 87 - 98% ⁽²⁾	Full Scale Treatment Systems (Population 235 - 8,400) Full Scale Treatment System (size not stated) Pilot Plant & Full Scale Treatment Systems (Pop. 8,400 - 25,000) Full Scale Treatment Systems (Pop. 39-15,000)
Radium 228	Same as Radium 226			
Radon 222	Aeration Packed Columns Diffused Aeration	Up to 99.9% ⁽²⁾	99% ⁽²⁾ 97% ⁽²⁾	By Comparison to Other Highly Volatile Organic Compounds. Field Tests Full Scale Aeration Plant
Thorium 230, 232	Not Established ⁽⁶⁾		Unknown	No Data Available ⁽⁷⁾
Tritium	Not Established ⁽⁶⁾		Unknown	No Data Available
Uranium	Ion Exchange Lime Softening Reverse Osmosis Coagulation/Filtration	65 - 99% ⁽²⁾ 85 - 99% ⁽²⁾ 98 - 99.4% ⁽²⁾ 80 - 95% ⁽²⁾	35 - 99% ⁽²⁾ 11 - 100% ⁽²⁾ 97 - 99.5% ⁽²⁾ 18 - 100% ⁽²⁾	Laboratory and Pilot Plant Studies Jar and Laboratory Scale Tests Laboratory and Full Scale Tests Jar, Laboratory Scale Tests and Full Scale Conventional Water Treatment Plants
Americium-241	Not Established ⁽⁶⁾		Theoretical ⁽⁷⁾ > 99%	Theoretical Calculations
Plutonium 238, 239 & 240	Not Established ⁽⁶⁾		Up to 99.9% ⁽¹⁰⁾ 25 - 96% ⁽¹⁰⁾	Laboratory Data for Reverse Osmosis Study of 6 WTPs Very Little Data Available ⁽¹¹⁾
Strontium-90	Lime Softening Ion Exchange (Mixed Bed)		Up to 99.7% ⁽¹²⁾ 90 - 99% ⁽¹⁰⁾	Laboratory Tests Unavailable

Footnotes for Table 8

- (1) The range of removal rates shown in this column corresponds to the actual studies shown to the right.
- (2) From "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule" (Federal Register, July 18, 1991).
- (3) From Technologies and Costs for the Removal of Radium from Potable Water Supplies (U.S. EPA, July 31, 1984).
- (4) From Water Treatment Plant Design. (ASCE/AWWA, 1990).
- (5) From Technologies and Costs for the Removal of Radon from Potable Water Supplies (U.S. EPA, April 25, 1988).
- (6) Based on pertinent research (see references section) there is very little available data related to the removal of these radionuclides.
- (7) From Technologies and Costs for the Removal of Alpha Emitters from Potable Water Supplies (U.S. EPA, February, 1991).
- (8) From Technologies and Costs for the Removal of Uranium from Potable Water Supplies (U.S. EPA, October 30, 1985).
- (9) From "Evaluation of Treatment Alternatives for Stormwater In Ponds A-4, B-5 and C-2" (IT Corporation, November 1, 1990). Prepared for EG&G Rocky Flats Plant, Inc. Rocky Flats Plant Golden, Colorado.
- (10) From Technologies and Costs for the Removal of Man-Made Radionuclides from Potable Water Supplies (U.S. EPA, March 10, 1986).
- (11) Based upon information in (7).
- (12) From Water Quality Treatment (AWWA, 1990).

Reference: Wright Water Engineers, Inc. 1992

TABLE 9
SUMMARY OF TECHNOLOGY AND PERFORMANCE
OF PROCESSES FOR REMOVING RADIONUCLIDES
FROM DRINKING WATER*

Radon		Radium		Uranium	
Method	Efficiency	Method	Efficiency	Method	Efficiency
Aeration		Ion exchange	81-99	Ion exchange	90-100
Packed tower	to 99+	Reverse osmosis	90-95+	Lime softening	85-99
Diffused bubble	to 99+	Lime softening	80-92	Reverse osmosis	90-99
Spray	70-95+	Electrodialysis	90	Coagulation-filtration	80-96
Granulated Activated		Ra complexer	90-99	Activated alumina	90
Carbon	62-99+	Greensand	25-50		
Adsorption-decay		Hydrous Manganese	90		
		Oxide-filter			

*The highest efficiencies for some technologies are associated with Point of Entry (POE) and Point of Use (POU) devices.

Reference: AWWA 1993.

901-004\460cb\Table-9

FIGURE 2



SHOWING SAMPLE LOCATIONS.

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4.2.1.3 Point of Use Drinking Water Facilities

The EPA sponsored a study for a small full-scale anion exchange system for the removal of uranium in groundwater used by the Jefferson County, Colorado School District. Four full-scale ion exchange systems were installed on four separate wells with yields of 5 to 10 gpm. The treatment system consisted of two cartridge type pre-filters in parallel, a two-tank commercial water softener system arranged in series, a brine tank to batch regenerant, and facilities to store and transfer spent regenerant.

Study results showed that greater than 99 percent of the uranium and between 85 and 94 percent of gross alpha in the groundwater influent was removed by the system, although a breakdown of removal effectiveness for the prefilters versus the ion-exchange columns was not calculated. A summary of the operating characteristics and study data is presented in Tables 10 and 11 (Jelinek and Sorg 1988). All effluents met proposed SDWA standards. During the study period, the system was regenerated twice using a salt (NaCl) regenerant solution. Analysis indicated that 97 percent and 66 percent of the uranium loaded on the resin was removed during the first and second regenerants, respectively. The capital cost for each system was approximately \$9,000 in 1986.

4.2.2 System Performance at Nuclear Power Plants

Nuclear power plants generate low level radioactive wastewater from a variety of sources. Water sources include primary cooling water, reactor cooling water, and wastewater from floor drains, sumps, laboratory effluent, laundry operations and decontamination areas. Except for radioactive constituents, most power plant waste waters are relatively clean, having very little suspended solids. As a result, treatment technologies applied to these sources are generally limited to ultrafiltration, demineralization via ion exchange, reverse osmosis, and evaporation. Dilution with clean cooling water or with source water from a river or other water source has also been used.

Nuclear power plant effluent must satisfy the regulations and guidelines of the Nuclear Regulatory Commission (NRC) and Title 10 of the Code of Federal Regulations (CFR), Part 20 (10 CFR 20). NRC effluent standards for water are given in Table 12. Numerous reactors achieve greater than 99 percent removal of fission products, and meet imposed effluent standards using a system featuring demineralization (ion exchange) and ultrafiltration. Since 1985, nuclear plants both domestic and international have changed over to glass fiber and nylon filter media that feature positive zeta potential to achieve greater reductions in radioactivity levels of cooling

TABLE 10
URANIUM CONCENTRATION REMOVAL
COAL CREEK ELEMENTARY SCHOOL

Sample Date	Cumulative Volumes Treated (Gallons)	Bed Volumes After Regeneration	Uranium Concentration (µg/L) ¹			
			Raw Water	After Column No. 1	After Column No. 2	% Removal Across Column No. 1
7-2-87 ²	66,000	2,940	56.6	< 0.1	0.6	99.8
9-2-87	116,740	2,260	45.2	0.1	0.1	99.8
10-6-87	165,220	4,420	39.7	0.1	0.1	99.8
11-18-87	218,620	6,800	47.0	< 0.1	0.1	98.8
2-3-88	284,790	9,750	110.0	0.3	0.2	99.8

¹ 1 µg/L uranium equals approximately 1.5 pCi/L

² The first ion exchange column was regenerated on these dates.

Reference: Jelinek and Sorg 1988

901-004\460cb\Table-10

TABLE 11
GROSS ALPHA REMOVAL
COAL CREEK ELEMENTARY SCHOOL

Sample Date	Gallons Treated	Gross Alpha (pCi/L)			
		Raw Water	After Column No. 1	After Column No. 2	% Removal Across Column No. 1
4-15-87	DNA ¹	68 ± 9	10 ± 4	DNA	85
4-15-87	DNA	46 ± 8	3 ± 3	DNA	93
7-2-87 ²	66,000	34 ± 5	2 ± 1	2 ± 1	94
9-2-87	116,740	47 ± 5	3 ± 1	3 ± 1	93

Note: Equipment Specifications:

Well Pump Capacity	38 lpm (10 gpm)
Prefilters	2% operated in parallel, spiral wound. 1 micron pore operating.
Ion Exchange Vessels	2% operated in series, 0.4 m diff. x 1.3 or high (16-in. x 52-in. high).
Resin	Sybron ionac A642 ¹ (potable water grade), 85 L (3-ft ³) per vessel, 0.60-m (24-in.) depth.
Length of loading cycle before regeneration	60,000 Bed Volumes
Brine Tank	0.60-m dia. x 1.04-m high (24-in. dia x 41-in. high) 250 kg (560 lb) NaCl storage capacity.
Regenerant wastewater tank	1.9 m ³ (500 gal.) volume.

¹DNA = data not available.

²The first ion exchange column was regenerated on this date.

Reference: Jelinek and Sorg 1988

901-004\460cb\Table-11

TABLE 12
NRC's EFFLUENT STANDARDS FOR WATER

	Effluent Concentrations Water ¹	
	$\mu\text{Ci/ml}$	pCi/L
Common Radioactive Contaminants of Pressure Water Reactor Cooling Water		
Cobalt 58	2×10^{-5}	20,000
Cobalt 60	3×10^{-6}	3,000
Strontium 89	8×10^{-6}	8,000
Cesium 137	1×10^{-6}	1,000
Barium 140	8×10^{-6}	8,000
Other Radionuclide Effluent Limitations		
Plutonium 239	2×10^{-8}	20
Plutonium 240	2×10^{-8}	20
Uranium 233	3×10^{-7}	300
Uranium 234	3×10^{-7}	300
Uranium 238	3×10^{-7}	300
Americium	2×10^{-8}	20

¹If the identity of each radionuclide in a mixture is known but the concentration of one or more of the radionuclides in the mixture is not know, the GAC for the mixture shall be the most restrictive DAC of any radionuclide in the mixture.

If the identity of each radionuclide in the mixture is not know, but it is known that certain radionuclides specified in this appendix are not present in the mixture, the inhalation ALI, DAC, and effluent and sewage concentrations for the mixture are the lowest values specified in this appendix for any radionuclide that is not know to be absent from the mixture, or

If a mixture of radionuclides consists of uranium and its daughters in ore dust (10 μm AMAD particle distribution assumed) prior to chemical separation of the uranium from the ore, the following values may be used for the DAC of the mixture: 6E-11 μCi of gross alpha activity from uranium-238, uranium-234, thorium-230, and radium-276 per milliliter of air, 3E-11 μCi of natural uranium per milliliter of air; or 45 micrograms of natural uranium per cubic meter of air.

If the identify and concentration of each radionuclide in a mixture are known, the limiting values should be derived as follows: determine, for each radionuclide in the mixture, the ratio between the concentration present in the mixture and the concentration otherwise established in Appendix B for the specific radionuclide when not in a mixture. The sum of such ratios for all of the radionuclides in the mixture may not exceed "1" (i.e., "unity").

Reference: 10 CFR 20, App.B

901-004\460cb\Table-12

water discharges (Weber 1989). These ultrafine filters are installed either upstream or downstream of ion exchange demineralizers depending on the application. Installed upstream, filters of 5 to 40 micron absolute rating provide greater service life and efficiency for the ion exchange columns. Installed downstream, filters of 0.2 to 0.6 micron absolute rating provide final polish prior to discharge.

Filters installed at Duke Power (Weber et al. 1989) found that a positive zeta potential filter media provided superior primary water decontamination than similarly rated filters without a positive zeta potential. In this study, the subject material for filtering was Co-58, and test water was passed through 0.1, 0.45, 1, 2, 5, 6, and 10 micron absolute filters. Non-positive zeta potential filters reduced the filtrate activity concentration from $1.1 \times 10^{-2} \mu\text{Ci/mL}$ ($1.1 \times 10^7 \text{ pCi/L}$) to a sample count of approximately $1 \times 10^{-3} \mu\text{Ci/mL}$ ($1 \times 10^6 \text{ pCi/L}$) for filter sizes from 0.1 to 5 microns. Positive zeta potential filters reduced the filtrate activity concentration from $1.1 \times 10^{-2} \mu\text{Ci/mL}$ ($1.1 \times 10^7 \text{ pCi/L}$) to a sample count at or below the threshold level of $5 \times 10^{-7} \mu\text{Ci/mL}$ (500 pCi/L) across the 0.45 to 6 micron filter range.

The Epicor II ion exchange system was used at Three Mile Island for initial treatment of sump water and primary system water and for accident water clean-up. The design limits for Epicor II are combined specific activities below $100 \mu\text{Ci/mL}$ ($1 \times 10^{11} \text{ pCi/L}$) for a throughput of 10 gpm so that 80,000 gallons per month can be processed. Gross cesium and strontium removal are done in an ion exchange vessel with a prefilter liner. The liquids are then processed through a cation exchange vessel for further removal of cesium, strontium, and other ions. This system performed very well during clean-up of accident water and was able to process even relatively low concentrations of liquid water; 0.1 to $10 \mu\text{Ci/mL}$ (10^8 - 10^{10} pCi/L) (Weber et al. 1989).

4.2.3 System Performance - Environmental Applications

Both the uranium mining industry and the DOE weapons production complex treat wastewaters for radionuclides prior to discharging this water to receiving streams. For uranium mining facilities, there is an economic incentive to recover as much uranium as possible from water discharges, as this is a marketable product. These facilities generally have sophisticated treatment and recovery systems which have the added advantage of achieving excellent performance against imposed discharge standards. Uranium mining operations also do a fair amount of treatment for environmental reasons general to remediate groundwater contaminated by past tailing disposal practices.

Individual facilities within DOE's weapons production complex are beginning the process of cleaning up past contamination, thus, treatment technologies for removal of low levels of radionuclides from environmental waters are of great interest. Most of the recent installations of radionuclide treatment systems have been done at DOE sites, as has most of the research on emerging technologies, which are discussed later in this report.

To recover salable materials, uranium (and radium) mining/milling facilities use a combination of filtration and chemical methods to remove suspended material while maximizing the amount of recoverable product in dissolved form. The solution is then passed through ion exchange columns that remove the dissolved isotopes using proprietary exchange resins, followed by additional treatment steps to recover the chemical additives from the beginning of the process. For recovery operations, removal/recovery efficiencies are in the range of 90 to 100 percent. Treatment system effluent concentrations for uranium, radium, gross alpha, and gross beta rarely exceed the proposed drinking water standards, and effluent waters are commonly recycled.

Mining operations also treat for uranium as part of waste management or environmental remediation activities associated with tailings ponds discharges or groundwater remediation. Recovery of salable product is generally not the primary intent of these operations, although recovery is generally performed as a cost saving or waste minimization activity. Two examples are given below.

Homestake Mining Company in Grants, New Mexico has been conducting groundwater remediation near its uranium mine tailings ponds since 1975 at a flow rate of 300 gpm (Cellan 1994). They are treating primarily for the removal of uranium, selenium and molybdenum. Influent concentrations of TDS range from 5,000 to 12,000 mg/L, and uranium is typically 22 to 25 mg/L. The pH of this groundwater is adjusted prior to passing through sand filters. Ion exchange (IX) columns are selective for trivalent cations. The IX effluent contains molybdenum at 0.04 mg/L and selenium at 0.9 mg/L. Homestake recently added a 6 gpm reverse osmosis (RO) pilot plant to produce an effluent with uranium concentrations ranging from 0.02 to 0.07 mg/L. It was noted that the RO effluent quality deteriorates at higher temperatures. UMETCO in Gas Hills, Wyoming operates a similar treatment plant which produces an effluent with 0.2 mg/L uranium from an average influent concentration of 10 mg/L (15,000 pCi/L) (Hoffman 1994).

Another example of mine site remediation is one conducted by the Wyoming Department of Environmental Quality (DEQ) at the Bison Basin Mine (Catchpole et al 1991). Using funds from

the closed mine's reclamation performance bond, DEQ hired a contractor who treated groundwater for uranium removal in two stages. Groundwater containing approximately 25 mg/L uranium was pumped through ion exchange columns, then pH adjusted and passed through sand filters and cartridge filters. Reverse osmosis was used as a final polishing step to reduce total dissolved solids (TDS) and to further remove uranium. The treated water was injected back to the aquifer which was remediated to an average quality of 0.4 mg/L uranium and 826 mg/L TDS. Total removal efficiency of the system was approximately 99 percent.

A total of 114 million gallons of groundwater were treated over a 10-month period. The reverse osmosis (RO) units required frequent cleaning with a heated detergent solution due to colloidal clay particles. Each unit processed an average of 538,000 gallons of water between cleaning cycles.

The Rocky Flats Environmental Technology Site (RFETS) currently has three facilities in place that are nominally designed to mitigate radionuclides (and other pollutants) found in various waters on site. These facilities are associated with Operable Units (OUs) 1 and 2, and are detailed below.

OU 1 remediates groundwater for organic contaminants as well as low levels of metals and radionuclides. A peroxide pretreatment is used to remove organics. Four ion exchange columns are then used to treat for the latter, which include uranium, tritium, gross alpha, and gross beta. Influent total uranium concentrations average about 7 pCi/L with maximum values approximately 10 pCi/L. Effluent concentrations average 0.074 pCi/L with a precision of 0.194 pCi/L indicating removal efficiencies greater than 99 percent (Cirillo 1994). Removal efficiency was also reported for strontium as 99 percent. Gross alpha and gross beta removal efficiencies were not provided. This treatment system operates at 30 gpm, eight hours per day, five days per week.

The OU 2 Radionuclide Removal System (RRS) is a trailer mounted facility using chemical precipitation and filtration as primary unit processes. The RRS process is preceded by an equalization tank and followed by neutralization and granulated activated carbon (GAC). The pH of the process water is initially adjusted to approximately 4.5 with sulfuric acid. Ferric sulfate (commercial Ferrifloc™) is then added as a coagulant and co-precipitation agent. The pH is then raised to approximately 9.5 using lime, causing precipitation of the metal hydroxides and adsorbed radionuclides. Solids are allowed to settle in a concentration tank, with liquids pumped to three parallel paths of shell and tube filtration vessels. The shell and tube filtration vessels are

a proprietary design and use filtration membranes nominally rated at 0.1 microns. The system flow rate is 50 gpm. A diagram of the process is shown in Figure 3.

Influent effluent concentrations for the complete treatment train indicate gross alpha activity and uranium concentrations have been decreased by 67.8 percent and 81.1 percent, respectively. Removal efficiencies for the RRS without the followup GAC treatment were 33 percent and 49.5 percent. Influent concentrations are reported in the 5 to 10 pCi/L range. The data do not show significant removal of other radionuclides due to the low, near detection limit influent concentrations (DOE 1993b).

RFETS also maintains facilities for the treatment of accumulated storm water on a contingency basis. At present, treatment unit processes consist of particulate filtration followed by granular activated carbon (GAC). These treatment facilities are designed for the removal of non-specific suspended solids and organic chemicals, particularly herbicides and pesticides. Although not intended to provide radionuclide removal, some reduction in total radionuclide concentrations have been measured. Particulate filtration using 40 micron filter bags followed by 5.5 micron filter bags indicated an approximately 30 percent reduction in Plutonium-239 concentrations (Moritz et al. 1993). In addition, radioactivity measurements on backwash water from GAC units and on spent carbon has shown that GAC does remove some uranium by both filtration and adsorption (Pettis 1994). This finding is consistent with other studies (Sorg 1988; Rockwell 1989a).

A new treatment facility at the DOE Hanford Reservation, the "200 Area Effluent Treatment Facility" (ETF), is designed to remove organic compounds and radionuclides. Unit processes are filtration, UV oxidation, microfiltration, reverse osmosis and ion exchange. The ETF will treat 40 to 150 gpm in a batch mode and will achieve their standards for discharge (McDonald 1994). Performance data is given in Table 13.

The components of the primary treatment train are shown in Figure 4. The primary treatment train removes contaminants from the waste water to concentrations below discharge limits, while the secondary train processes the concentrated side streams. The filtration and microfiltration processes remove suspended solids, ultraviolet light oxidation is used to destroy organic compounds, and reverse osmosis (RO) and ion exchange (IX) is used to remove radionuclides and dissolved solids. In the secondary treatment train, evaporation and thin film dryers convert the liquid waste from these processes to a dry powder. The system is intended to produce an effluent

FIGURE 3
RFETS OPERABLE UNIT 2 TREATMENT SYSTEM

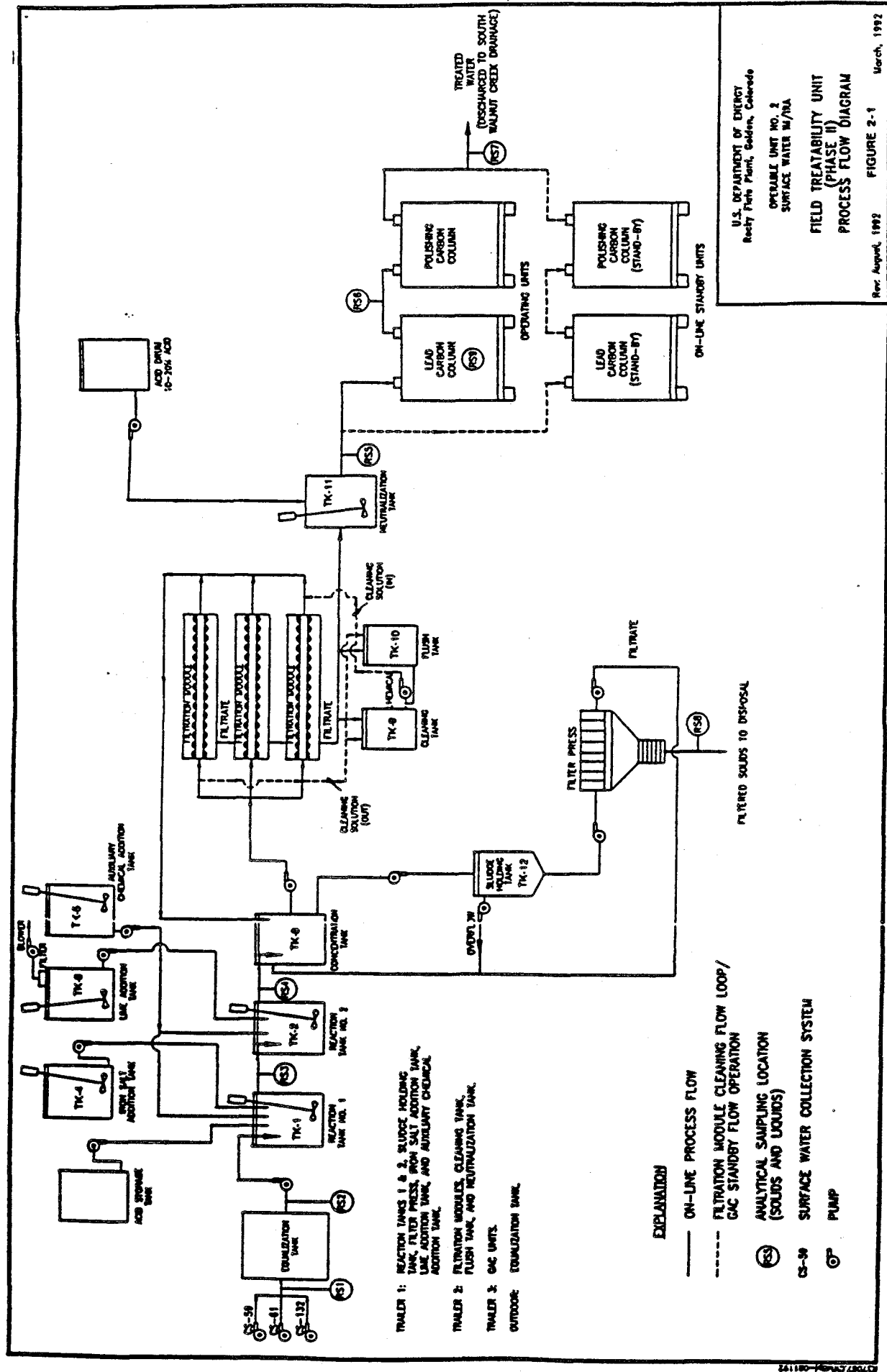


TABLE 13
RADIONUCLIDE REMOVAL PERFORMANCE TESTS
AT THE DOE HANFORD FACILITY

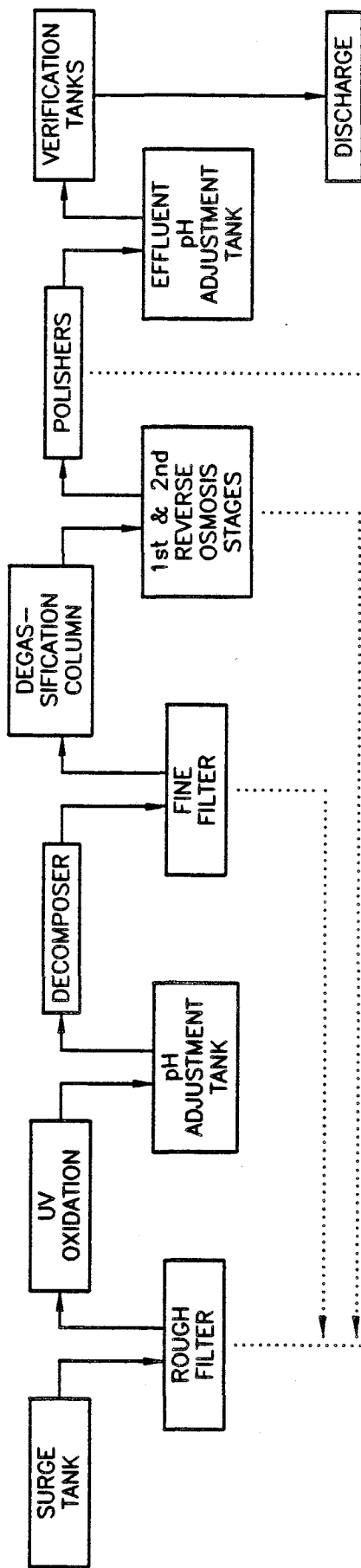
Type of Process	Type of Feed Water	Parameter	Feed (pCi/L)	Permeate (pCi/L)	Removal Efficiency (%)	ACV ¹ (pCi/L)
Full System	B Plant Condensate	Cesium	5,030	<45	>99.1	30,000
		Strontium	214,000	<149	>99.9	20,000
Full System	UO ₃ Process Condensate	Alpha	3,050	<23	>99.2	
		Beta	4,630	276	94.0	
		Technetium-99	1,350	<252	>81.3	4,000
		Tritium	5.6 E7	5.5 E7	-	
		Uranium	4,627	6	99.9	200
Full System	UO ₃ Process Condensate (pH adjusted to 5.0)	Alpha	379	<36	>90.3	
		Beta	12,600	3,680	70.8	
		Technetium-99	946	175	81.5	4,000
		Tritium	4.9 E7	4.9 E7	-	
		Uranium	3,180	11	99.6	200
Reverse Osmosis	Ground water (Well 200-W19-03)	Uranium	4,700	4.7	99.9	600 ²
		Technetium-99	1,219	57.3	95.3	900 ²
Reverse Osmosis	Ground water (HCl added to dissolve CaCO ₃)	Uranium	7.8 ppb	n/a	99.8	600
		Technetium-99	192.7 ppb	n/a	83.9	900
Reverse Osmosis	Purge water from well (Well 1-H3-2B)	Alpha	1.94	0.25	87.6	15 ²
		Beta	5.91	0.70	88.2	50 ²
		Uranium	2.58	0.45	82.5	600 ²

¹Administrative Control Value

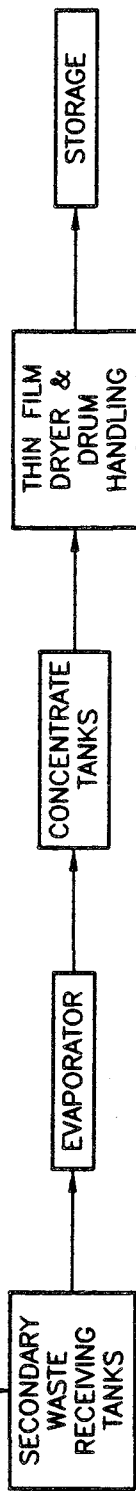
²Drinking Water Standard

Source: Garrett 1990.

PRIMARY TRAIN



SECONDARY TRAIN



WRIGHT WATER ENGINEERS, INC.
 2490 W. 26TH AVE. SUITE 100A
 DENVER, CO 80211
 (303)480-1700

FIGURE 4

**HANFORD DOE FACILITY
 EFFLUENT TREATMENT FACILITY FOR
 RADIONUCLIDE AND ORGANIC REMOVAL FROM WASTEWATER
 AUGUST 1994**

DRAWN	KAL
CHECK	DJB
DATE	11/10/94
JOB NO.	901-004.460

that need not be disposed of as a regulated waste. The "Delisting Petition" for this process from Westinghouse-Hanford (DOE 1992) details the management of this waste.

Pall Corporation supplied two automated, backwash filtration systems to Adtechs for service in the PUREX radwaste processing line. The intent of the filter systems is to remove particulate and ultimately to protect a reverse osmosis membrane. The systems, designated "rough" and "fine", were equipped with ProSep filter elements grades Y080 and Y045 respectively. The removal efficiency of the Y080 filter is 8 microns, BETA 1000 (99.9%) while the removal efficiency of the Y045 filter is 4.5 microns, BETA 1000 (99.9%). The filters will be challenged with organic and inorganic contaminants and must produce water with an SDI of less than 5. Solids loading will be in the PPM range (estimated load is 10 ppm or greater). Performance capability was verified in a proof-of-concept test.

The DOE facility at Savannah River, Georgia treats wastewater for U-238. The waste stream may have concentrations of U-238 up to 50 parts per million (ppm) (75,000 Pci/l) (Diener 1994). The processes used are summarized as follows:

1. The pH of the influent is reduced below 2 to drive off carbonate ions as carbon dioxide.
2. An influent storage tank maintains uranium in its nitrate form. Each batch is adjusted to pH between 6 and 8.5.
3. Batches will be pumped to a flocculation tank where alum is added to remove excess phosphate and to coprecipitate uranium as a metal phosphate. This is due to the presence of phosphates already in the waste stream. A polymer (Praestol® K290FL) and filter aid (perlite, replacing the previously used diatomaceous earth) are also added prior to pressure filtration.
4. Pressure filtration is performed using a tightly-woven 0.3 micron (nominal) belt fabric.

Filtrate effluent concentrations are less than the applied detection limit of 10 parts per billion (ppb) (15 pCi/L). This process is interesting from the standpoint that excellent removal of uranium is accomplished using conventional processes, without a subsequent need for ion exchange or reverse osmosis.

The liquid effluent treatment facility, at the Los Alamos National Laboratory in New Mexico, is treating wastewater at the rate of 120 gpm (in a batch process) to remove U, Pu and Am (Moss 1994). The treatment process consists of coagulation with lime, ferrifloc, and a cationic polymer. The water passes through a clarifier and a gravity filter. Filtrate is sent through ion exchange columns which are selective for cations and is then stored in a batch holding tank. Sludge is passed through a vacuum filter, and the final solids are drummed for shipment to the Waste Isolation Pilot Plant.

Total activity is reported to drop from 100 nCi/L (100,000 pCi/L) to 100 pCi/L, although influent and effluent concentrations vary greatly. Further research is being conducted on the use of oxidizing agents (ozone, peroxides, and permanganate), monitoring for removal efficiency, sludge reduction, and reduction of loading to the filters.

Los Alamos is also evaluating ultrafiltration (Spintex is the manufacturer) to help reduce americium which passes in a particulate form now. This process may also reduce scaling of the membrane and increase run times due to a design turbulence, or shear effect.

The DOE K-25 facility, approximately 10 miles northwest of Oak Ridge National Laboratory in Tennessee, has a waste water treatment plant which treats for uranium in a batch process (Kent 1994). Initially, the pH is lowered to drive off carbonates as carbon dioxide. This is followed by the addition of a base to raise the pH prior to coagulation with iron hydroxides. Performance information was not provided by Oak Ridge personnel.

Other DOE facilities across the United States were contacted in an effort to learn what their current practices were in water treatment for radionuclide removal. A representative for Mound facility in Ohio stated that Mound did not treat water for radionuclides, but did monitor for tritium. A representative for Argonne National Laboratory stated that he would be unable to share information with WVE without the likelihood of establishing a client relationship. Attempts were made to contact individuals at Lawrence Livermore National Laboratory, Pacific National Laboratory, and Fernald. Telephone messages were not returned.

4.3 EMERGING PHYSICAL TREATMENT/SEPARATION TECHNOLOGIES

Radionuclides to be separated from a water stream are often found as dissolved cations or anions and/or submicron particulates. In these forms, they are especially liable to be adsorbed to large surface area solid media, such as colloidal and other submicron solids which can present particularly stringent filtration requirements. For this reason, the long-standing specification of a 0.45 μm filter as the means of separating colloidal from particulate matter is not adequate for radionuclide filtration. For purposes of the following discussions, the terms below are adapted from recommendations in the Nalco Water Handbook, Chapter 44, Production of Ultrapure Water.

Particulate matter:	Filterable by a 0.22 μm filter.
Colloidal and dissolved matter:	Not filterable by a 0.22 μm filter.

4.3.1 Magnetic Filtration

Magnetic filtration was bench tested at RFETS in 1989. Magnetite (black sand) was extracted from Rocky Flats soil and separated into four size fractions. Solutions at pH 12.5 containing Pu-239 at about 10^{-4} g/L (6.22×10^6 pCi/L) and Am-241 at about 10^{-7} g/L (3.4×10^5 pCi/L) were mixed for 10 minutes and then magnetically filtered on a glass column packed with fine stainless steel wool. Actinide removal efficiency ranged from 98.4 to 99.8 percent, improving as the black sand particle size decreased. The best removal was with the finest particle size range of < 63 micron (Kochen and McGloughlin 1989).

At the time of publication of the report, a method for efficient regeneration of the ferrite-resin had not been developed and further studies were recommended.

At the Savannah River facility, future testing of a Mag-Sep® process will focus on removal of heavy metals in groundwater (Bibler 1994). This water contains high iron levels and a pH of around 2.3. A permeable wall will be placed below the water table in an excavation. Inside this wall, magnetic particles will be circulated and subsequently removed and treated with either nitric acid or sodium hydroxide, depending on the sorber used. The magnetic particles are then recirculated. Other resins may be tested that are contaminant specific.

4.3.2 Sub-micron Particulate Filtration

A study of particle sizes for primary coolant radioactivity at the Northeast Utilities Millstone 3 nuclear power plant showed that over 50 percent of fission product radioactivity in cooling water is associated with particles less than 0.4 microns in size (Weber et al. 1989). Other studies in Germany reported approximately 70 percent of cobalt contamination was associated with particle sizes less than 8 microns (Weber et al. 1989). Studies of RFETS pond water conducted by Los Alamos National Laboratory (based on limited data) indicated that 60 to 80 percent of plutonium is associated with the greater than 0.45 micron size fraction, but that a significant amount (17 to 32 percent) is in the soluble (less than 2 nanometer) fraction (Polzer 1992).

Numerous filter manufacturers have developed or are developing cartridge type particle filters with claimed absolute filtration ratings below the nominal "filterable" range of 0.22 μm . Many of these filters are designed to be backwashable for long service life. The Pall Corporation offers a backwashable glass fiber cartridge filter with a 0.2 μm absolute rating under the trade name Ultipor GF Plus. The filters provide a positive zeta potential and are resin-bonded glass fibers that are of a polymeric substrate material. Pall Ultipor N66 and N66 Posidyne pleated nylon membrane filters are available in a claimed absolute rating down to 0.04 μm . Environmental applications of these filters hold significant potential. Potential applications include improved filtration upstream of ion exchange beds or reverse osmosis, or as a final polish after other filtration methods.

RFETS recently completed an ultrafiltration/reverse osmosis pilot test on natural pond water at a flow rate of 5 to 6 gpm. Performance results are given in Table 14. Ultrafilters nominally rated at a 80,000 Molecular Weight cutoff achieved removal efficiencies of 63 percent to 72 percent for gross alpha, gross beta and uranium for influent concentrations below 10 pCi/L. Average system removal efficiencies were greater than 99 percent for uranium and gross alpha, and approximately 94.2 percent for gross beta. Removal efficiencies for plutonium and americium were not calculable due to low influent concentrations.

Early tests of reverse osmosis for plutonium and americium removal were also performed at RFETS in 1979 and 1980 (Plock et al. 1981).

A mobile RO pilot plant was successfully used to clean up radionuclide contaminated storm water runoff collected in impoundments. 4000,000 gallons of a caustic water slightly contaminated with low concentrations (not quantified here) of uranium, plutonium, and americium were processed

TABLE 14
ULTRAFILTRATION AND REVERSE OSMOSIS
PILOT TEST¹ AT THE ROCKY FLATS ENVIRONMENTAL
TECHNOLOGY SITE

Contaminant	Removal Efficiencies (%)					
	Ultrafiltration		Reverse Osmosis ²		Total System	
	Range	Average	Range	Average	Range	Average
Gross Alpha	50-75	63	90-99.9	97.4	96.7-99.9	99.1
Gross Beta	55.9-90	71.8	65-90	78.8	91.1-98	94.2
Plutonium-239/-240	²	²	²	²	²	²
Americium-241	²	²	²	²	²	²
Uranium-233/-234	60.6-70.9	66.2	94-99.9	97.9	98.2-99.9	99.4
Uranium-238	56.7-70.6	64.6	94.8-99.9	98.3	98.5-99.9	99.6

¹Summary of four tests conducted 8/17/94 through 8/25/94.

²Raw water concentrations too low to calculate removal efficiencies.

³Listed reverse osmosis removal efficiencies are for the fraction of radionuclides remaining after ultrafiltration.

Reference: (Moritz 1994)

by the pilot RO plant at a rate of 26,000 gpd with 98 percent recovery. Concentrations of plutonium and americium were reduced to less than 1 pCi/L in the product water. Concentration of uranium was reduced by greater than 99 percent to 4.4 pCi/L.

Subsequent testing of this RO pilot plant on pond water required feed water to be pretreated by four stages of filtration, Ca removal, preheating, pH adjustment, and chlorine addition. Even with this level of pretreatment, the filter service life was rather short, ranging from just a few hours to two days, depending on the season and environmental conditions. Membrane scaling by microorganisms and by iron and silica deposits, also occurred, indicating that additional pretreatment would be beneficial.

Pilot testing of reverse osmosis to remove radionuclides from various waste streams and groundwater has also been performed at the Hanford facility (Garrett 1990). The membrane used was Filmtec® FT-30, a thin film composite polyamide. Removal efficiencies ranged from 82.5 percent to 99.99 percent with the highest removal efficiencies occurring for the highest influent concentrations. A summary of the tests is shown in Table 13.

4.4 EMERGING CHEMICAL TREATMENT/SEPARATION TECHNOLOGIES

4.4.1 Ferrite Precipitation/Coprecipitation

Ferrite precipitation/coprecipitation works by electrochemically bonding dissolved radionuclides to iron hydroxide molecules at high pH, and adjusting the pH to form oxide particles which will then precipitate taking the attached radionuclide with it. This process is affected by the presence of competing ions such as phosphate, beryllium, fluoride, silicate, and arsenate, which interfered with ferrite formation and subsequent actinide removal. Detergents and complexing solvent extractants also seemed to interfere with ferrite formation to some degree.

Bench studies at Rocky Flats showed that plutonium concentrations could be reduced from 10^{-4} g/L (6.22×10^6 pCi/L) to the 10^{-8} g/L (622 pCi/L) range in one treatment step (Boyd et al. 1985). *In situ* and preformed ferrite were about equally effective at removing Pu in the absence of interfering ions. *In situ* ferrite was much more sensitive to the presence of interferences, and the preformed method was more sensitive to the presence of detergents. Although these final concentrations are much higher than the required levels, this process may have application as a pretreatment step in a multistage treatment process.

In a separate bench scale test (Kochen and Henry 1987) uranium in pond water, adjusted from pH = 8.4 to pH = 12.0, was lowered from 23 pCi/L to about 0.2 pCi/L when the water was treated with commercial magnetite (a particular form of ferrite) activated with barium hydroxide and sodium hydroxide. At pH = 12, magnetite activation with $\text{Ba}(\text{OH})_2$ was about ten times more effective than NaOH activation. At pH = 8.4, the natural pond pH, both methods of activation resulted in ineffective uranium removal. No attempts were made to find the optimal pH or magnetite concentration.

4.4.2 Ferrate Precipitation/Coprecipitation

A formulation of potassium ferrate (K_2FeO_4) and magnesium salts was evaluated for removal of low levels of uranium from aqueous waste streams at the Fernald Environmental Management Project (FEMP) near Cincinnati, Ohio (Potts and Hampshire 1993). In these tests, potassium ferrate appeared to be a more efficient coagulant than aluminum, ferric, or ferrous salts.

Jar tests were initially conducted to simulate a one or two stage clarification treatment process. Before addition of the potassium ferrate, pH was adjusted to the range of 10.6 to 11.2 with sodium hydroxide to force dissolved uranium to convert to uranyl hydroxide which is more easily coagulated than soluble uranium carbonate complexes. Influent uranium concentrations ranged from 62 to 490 $\mu\text{g/L}$ (93-735 pCi/L). Chemical addition was 120 mg/L potassium ferrate solution also containing a minor amount of magnesium salts. Magnesium salts act as a seed crystal to ensure formation of colloidal particles and promote floc formation. Removal efficiency was 72 to 86 percent during the first stage, and approximately 98 percent when treated a second time with the same solution. All tests achieved discharge values below 20 $\mu\text{g/L}$ (30 pCi/L), the current proposed MCL for uranium.

Follow-up pilot tests at an operating wastewater treatment plant (Plant No. 8) at Fernald showed better than 94 percent removal efficiency. No flow rate was specified for the pilot test, however, annual costs for treatment using this process were estimated at \$.08 per gallon for a 6.2 million gallon annual throughput. Treatment costs are given in Table 18. Initial equipment/startup costs were not given, since the potassium ferrate would essentially replace previously used chemicals and no new equipment would be needed.

Jar tests of potassium ferrate for removal of americium and plutonium have also been conducted at an undisclosed DOE facility (Potts and Churchwell 1994). Pu and Am were reduced from 37,000 pCi/L to less than 40 pCi/L, a removal efficiency of over 99 percent. The formulation

of potassium ferrate used in these tests was a proprietary mixture known as "TRU/Clear #4", at 14-15 percent by weight.

4.4.3 Ion Exchange Improvements

Although simultaneous exceedances of both the radium and uranium MCLs are infrequent, it is prudent when removing one radionuclide to consider removing both. Uranium and radium are often found in close proximity to each other because uranium-238, uranium-234, and radium-226 are in the same decay chain, and both add to general gross alpha and gross beta contamination. Recent studies have shown that adding a small amount of strong base anion (SBA) resin to the strong acid cation (SAC) resin in a conventional ion exchange column provided good combined radium and uranium removal (Clifford and Zhang 1994). In tests on well water containing 25 pCi/L of radium and 120 ug/L (180 pCi/L) uranium, a mixed bed containing 10 percent SBA and 90 percent SAC resin yielded an effluent water with less than 1 pCi/L radium and less than 20 ug/L (30 pCi/L) uranium.

A modification to the magnetite process, discussed previously, involved attaching magnetite to the surface of a anion exchange resin (EG&G 1992) and operating in a column mode. Two advantages were realized from this approach:

1. Because the adsorbent medium was retained in a column, there was no need to remove magnetite particles from the treated water.
2. Much less magnetite is needed for the same removal efficiency when the magnetite is attached to a resin surface rather than used alone. Twenty grams of magnetite-coated resin were as effective as 650 grams of free magnetite at removing plutonium and americium.

4.4.4 Coagulants/Flocculants/Adsorbents

There are basically two ways to operate an adsorption process for radionuclides. The most common method is to mix the adsorption media into the waste water stream, precipitate the media containing the adsorbed contaminants, and remove both media and contaminant with conventional clarification/filtration steps. The second method of conducting an adsorption process is to pass water through a solid phase adsorptive bed. Waste waters pretreated with conventional

coagulation/ flocculation/ clarification processes are filtered through a media in a column or a bed that provides adsorptive capacity as well as filtration.

Various new and modified sorption media have been tested for their effectiveness in removing radionuclides, metals, and other inorganics from aqueous solutions. Tests have included ferrite (Boyd et al. 1985), activated magnetite (a particular form of ferrite) (Kochen and Henry 1987), granular activated carbon (Kochen 1989) non living biomass (known as Metal Recovery Agent - MRA) (Kochen 1989b), sand coated with oxide materials (Stenkamp and Benjamin 1994), bone char (Barney, Lueck, and Green 1992), and miscellaneous proprietary media such as Filter Flow 1000™. Most of these processes require strongly basic conditions (pH more than 10 or 12), show removal efficiencies of 90 to 99 percent, and can be easily adapted to current treatment processes and equipment.

Colloid Filter Polishing Method

The Colloid Filter Polishing Method (CFPM) was bench tested at RFETS, OU 4 in 1993 and is scheduled for full implementation this year (DOE 1994a). This process removes inorganic heavy metals and radionuclides from water, using a filter bed material contained in a dynamic, flow-through configuration resembling a filter plate. The process is described as a two-step procedure: 1) prefiltration (or clarifier removal) of bulk solids; and 2) sorption and chemical complexing of the contaminants in a filter bed comprised of a proprietary mixture of inorganic, insoluble oxide, silica and quartz materials in granular form (Filter Flow 1000™). The bed material has high affinity for inorganic metallics, especially higher valence forms, chelated and complex forms including the radionuclides.

Bench scale study of the method was performed on intercepted groundwater. Equipment consisted of an air pump, pre-filter (10 micron filter bag), and the CFPM filter unit. The Filter Flow bed material was made into a slurry and poured into the filter unit. The influent was frequently stirred and pumped through the pre-filter and then through the bed material. Flow rate was 150 to 200 ml/min. and pH of the effluent was 12.2 to 12.7. Eight runs were performed under the various conditions of pH and contact time.

In each run, the influent (INF) or intermediate (prior to entering the filter bed) (INT) and the effluent (EFF) were collected and analyzed. Performance results are given in Table 15. Errors are associated with the values at 2 confidence levels (95 percent). Negative values in the effluent reflect statistical fluctuations and detection limits of 0.05 pCi/L (Laul et al. 1992).

TABLE 15
RESULTS OF CFPM PILOT TEST AT OU 4

Table 3. BENCH SCALE STUDY RESULTS^a
(PC/L)

Experiment		U-238	U-234	Pu-239	Am-241	Gross Alpha	Gross Beta
Run-1 as such	INF	35.0+ 6.5	56.0+ 10	6.8 + 1.2	22.0+ 3.8	166+ 15	124+ 8
	EFF	-.01+ .03	-.03+ .03	-.01+ .02	-.01+ .01	23+ 6	57+ 7
Run-2 pH8 + S.S	INT	31.0+ 5.4	49.0+ 8.2	3.8 + .76	1.2 + .41	46+ 5	34+ 5
	EFF	-.01+ .03	.02+ .04	-.02+ .02	.043+ .03	17+ 5	54+ 9
Run-3 pH9 + R.A + S.S	INT	32.0+ 6.0	50.0+ 9.0	8.1 + 1.4	4.3 + .85	133+ 13	99+ 12
	EFF	.03+ .05	.04+ .06	-.02+ .01	.01 + .02	18+ 6	63+ 8
Run-4 pH9 + S.S	INT	31.0+ 4.5	51.0+ 7.1	4.9 + .84	3.4 + 1.1	89+ 11	62+ 8
	EFF	.01 + .03	-.02+ .03	-.03+ .01	-.01+ .02	21+ 5	55+ 9
Run-5 pH8 + R.A + S.S	EFF	-.01+ .03	-.01+ .04	-.02+ .02	-.01+ .01	34+ 4	73+ 8
Run-6 pH9 + R.A + S.S Fast Flow Slow Flow	INF	12.0+ 2.2	18.0+ 3.3	22.0+ 3.5	26.0+ 3.8	82+ 8	44+ 8
	INT	7.5+ 1.2	12.0+ 2.0	9.0 + 1.3	6.0 + 1.2	42+ 4	20+ 7
	EFF-1	.01+ .03	.01+ .03	-.01+ .02	.015+ .02	24+ 5	31+ 6
	EFF-2	.02+ .03	.01+ .03	-.01+ .02	.03 + .03	13+ 4	24+ 7
Run-7 Minerals pH9 + R.A + S.S	INT	11.0+ 2.1	17.0+ 3.1	14.0+ 2.3	(17 + 5.8)	85+ 9	42+ 6
	EFF	-.01+ .03	-.01+ .04	.01 + .02	.059+ .052	19+ 5	34+ 7
Run-8 Overnight Equil. + S.S	INT	3.3+ .82	5.1+ 1.1	6.1 + 1.0	9.2 + 2.4	46+ 8	35+ 8
	EFF	-.01+ .03	-.01+ .03	-.01+ .02	.05 + .04	14+ 3	31+ 5

^a Tracers used: U-232 (4.7pc), Pu-242 (4.0pc), Cm-244 (4.5pc).
200 ml was taken for INF and INT; 1 litre for EFF. Values in () shows poor yield.
S.S= Sodium Sulfide; R.A= Reducing agent - Sodium bisulfite

Source of Table: Laul et al. 1992.

Removal efficiencies > 99% for U-238, U-234, Pu-239, Am-241.

Gross Alpha Removal Efficiency 48.8% - 86.5%, Avg. = 37.7%.

Gross Beta Removal Efficiency 11.3% - 54.6%, Avg. = 31.1%.

Granular Activated Carbon

An upflow column experiment showed that GAC could remove 92-95 percent of the Pu, Am, and U from water solutions containing about 10^7 pCi/L of Pu and 10^6 pCi/L Am at pH 7.3 (Kochen 1989). In a separate experiment, 99 percent of the uranium was removed from a solution containing 50 pCi/L U-238 and 50 pCi/L U-234 at pH 7.3. It was pointed out that if both volatile organic compounds and radionuclides are removed on the same GAC column, a mixed waste is produced that requires special handling and storage.

Metal Recovery Agent (MRA) is a non-selective sorbent that operates by ion exchange and sorptive mechanisms. There are two separate modifications of MRA, one for oxy-anions and one for cations.

Batch test experiments of MRA were conducted at pH 4.0, 7.0, and 9.0, with a water solution containing Pu-239 at about 5 μ Ci/L and Am-241 at about 0.5 μ Ci/L (Kochen 1989b). A column test at pH 7.5 was conducted with a solution containing Pu-239 at 7.2 μ Ci/L and Am-241 at 1.5 μ Ci/L. Batch tests removed about 95 percent of the Pu and Am at pH 4.0 and 7.0, but only 60-70 percent at pH 9.0. The column test at pH 7.5 removed about 90 percent of the Pu and Am. Actinide removal efficiency of MRA is similar to that of activated granular carbon.

Bone Char

In comparative tests, bone char was found to be more effective in column experiments for adsorbing plutonium from a waste water containing about 1 μ Ci/L (1000,000 pCi/L) Pu-238 than nine different commercially-available adsorbents (Barney, Lueck, and Green 1992). The comparison commercial adsorbents fell into four general classes:

- (1) chelating heavy metal removal agents
- (2) cation exchange resins
- (3) anion exchange resins, and
- (4) activated alumina and carbon adsorbents

In the bone char flow-through column tests, plutonium decontamination factors were between 400 and 3,000, depending on flow rate. Among the commercial adsorbents, the highest decontamination rate was 77 for Duolite GT-73, a cation exchange resin.

Partition coefficients (defined as $K_d = (\text{Pu activity per gram wet adsorbent})/(\text{Pu activity per mL solution})$) for the bone char in batch equilibrium studies ranged from 8,000 mL/g to 31,000 mL/g for pH values between 5 and 9, with the highest sorption occurring at pH 8. High partition coefficients (4000 mL/g to 7000 mL/g) were observed also for Bioclaim MRA, a chelating heavy metal removal agent, but Bioclaim MRA did poorly in the flow-through column experiments because the rate of sorption was slow.

In these tests, bone char appeared to be the most effective adsorbent for removal of plutonium because of high partition coefficients and rapid adsorption. The authors estimated that 1 kg of bone char would treat 30,000 L of wastewater. For an estimated activity in the feed water of $4.3 \times 10^{-4} \mu\text{Ci/L}$ (430 pCi/L), the authors calculated a residence time in a bone char column of about 2 minutes would establish an effluent activity of $2.6 \times 10^{-6} \mu\text{Ci/L}$ (2.6 pCi/L). Their data indicates that a column residence time of 10 minutes would produce an effluent activity of about $10^{-7} \mu\text{Ci/L}$ (0.1 pCi/L).

Other Adsorbents

Bench testing of six commonly available adsorbents was also conducted at RFETS in 1993 to determine removal efficiencies for a variety of metals and radionuclides. A mixed metal oxide (SORBPLUS) and a granular activated alumina (F-1) showed 99 percent removal of total uranium for an influent concentration of 3.1 $\mu\text{g/L}$ (4.6 pCi/L) (DOE 1994). Performance data for other radionuclides was inconclusive due to low influent concentrations.

4.5 BIOLOGICAL TREATMENT TECHNOLOGIES

4.5.1 Biosorption

The only studies found on biosorption processes for radionuclides focussed on nuclear power and/or reprocessing plant effluent containing isotopes of cobalt, strontium, cesium, and ruthenium. Studies on biosorption of plutonium, americium, or uranium were not found in the literature. Bench scale research (Barratt 1990) showed three fungal isolates, *Trichoderma viride*, *Penicillium expansum*, and *Aspergillus niger*, were effective in removing strontium, cobalt, and ruthenium at influent concentrations of 1-10 mg/l, but were ineffective at higher concentrations. *T. viride* and *P. expansum* both showed 100 percent removal (note: no detection level specified, analysis done with AAS) of strontium and cobalt at concentrations of 10 mg/l, and *A. niger* showed 50 percent removal of ruthenium at a concentration of 10 mg/l.

Biosorption processes must be followed by a filtration step, thus the removal efficiency of this technology will be dependent on both the uptake potential of the organism, and on the efficiency of the filtration process used to remove the biomass. Research indicates that biosorption processes for transuranic elements are possible, but will most likely be dependent on identifying a specific organism that has an affinity for the element to be removed. This technology is not viable at this time for environmental levels of transuranic elements.

4.5.2 Metal Immobilization by Bacteria

Bacteria can actively or passively immobilize metals. Active immobilization by bacteria occurs during metal transformation or microbe interactions such as (1) precipitation, (2) intracellular accumulation, (3) oxidation and reduction, and (4) methylation and demethylation by active microorganisms. Passive immobilization by bacteria occurs by physical and chemical reactions such as chelation or binding by physical chemical reactions that do not necessarily require living microorganisms.

Living bacteria have the following advantages for the treatment of metals: (1) the biological adsorbent is a renewable resource that does not need to be replaced, and (2) products of metabolism can be used in the metal immobilization process. Disadvantages of using living adsorbents for industrial use and for process water treatment include: (1) high metal levels are toxic to living microorganisms, (2) surface-active agents and other factors such as pH and salt concentrations in the effluents can produce variability in effectiveness, (3) maintenance of the growth and activity of the selected microorganisms, and (4) production of the biomass.

Studies have found that bacteria can accumulate a variety of radionuclides; however, more study needs to be done on the long-term effect of high-level radiation on the stability of biosorbent products (Brierley 1990). Additionally, the efficiency of metal removal of achieving high removal rates are dependent on (1) the initial metal concentration, (2) other ions present, (3) complexing or chelating agents, and (4) displacement of one metal with another metal at the biosorbent binding site. If the initial metal concentration is low, the removal rates are not as efficient. Likewise, if other ions and complexing or chelating agents are present, they may compete for binding sites on the biosorbent material. An increase in contact time between the aqueous solution and the adsorptive material or treat industrial effluents with a combination of technologies can result in the achievement of the regulatory discharge limits. However, the lower the metal loading (i.e., the lower the metal concentration in the solution), the higher the operating and capital costs (Brierley 1990).

4.5.3 Wetland Treatment

Currently, much research is being conducted regarding the precipitation of metals by activities of sulfate-reducing bacteria for the treatment of soluble metals from acid mine drainage. One of the most important mechanisms from metal removal in wetlands is the proliferation and activity of sulfate-reducing bacteria. Sulfate-reducing microorganisms in wetlands should actively accumulate and passively bind metal ions when a system is functioning as a wetland. In most constructed wetland systems, it appears that the principal metal-removal mechanism is the oxidation of iron that is bacterially catalyzed. Additionally, bacterial sulphate reduction is another reaction. The process of adsorption, ion exchange, and complexation with organic material also plays a role in metal removal (Perry and Kleinmann 1991).

Studies have also found that many wetland plants are capable of accumulating high concentrations and quantities of metals in live root and leaf material (Cooper 1987). A common dominant of Rocky Mountain fens, *Carex aquatilis*, was found to have the ability to accumulate high concentrations of metals in the roots and leaves and is acid-tolerant. The level of accumulation of metals by wetland plants varies depending on the specific metal and species of plant.

4.5.4 Fungi and Yeast Metal Uptake

Several studies have analyzed the uptake of radionuclides such as uranium and thorium by fungal biomass. Most of these studies have involved dead biomass and it appears that metabolism-independent biosorption is the main mechanism of uptake even in living cells. It has been found that the radionuclide uptake capacity can be large, as with heavy metals. The uptake capacity is affected by pH, temperature, and the presence of other chemical species (Gadd 1990). The following processes can increase the capacity of the biomass for radionuclide adsorption: (1) selection of a killing treatment that maximizes capacity, (2) powder the dried biomass to increase the number of availability of binding sites, and (3) treatment with a detergent to increase binding sites.

Metabolism-dependent intracellular (active) uptake is different from metabolism-independent (passive) adsorption because metal ions are transported into the cells across the cell membrane. This process is slower than adsorption and may be limited by low temperatures and the absence of an energy source such as glucose.

As an example of industrial application of radionuclide uptake, McCready and Lakshmann (1986) found that uranium removal rates by *R. arrhizus*, grown in an airtight fermentor, were higher in comparison as compared to ion exchange and reverse osmosis processes (Gadd 1990).

4.5.5 Metal Uptake by Algae

It has been found that both living and nonliving algae have metal binding capabilities that are similar to ion-exchange resins (Greene et al 1990). Binding can occur either biologically (active) or by physical/chemical processes (passive). The biologically active algal cells may bind metals by surface binding, precipitation, or by intracellular transport and chelation. Biologically inactive cells uptake may involve covalent or electrostatic binding to cell surfaces or by chemical redox interactions between the metal ion and the algal cells (Greene 1990). The use of living algae is limited in several ways such as (1) the inability to recover metals from metal-saturated cells while maintaining their viability, (2) the toxic effects of the metals on cell growth and viability, and (3) the ability to prepare adequate biomass for treatment purposes.

Biologically activated carbon (BAC) is active carbon that has been colonized by microorganisms such as algae. The possibility of removal of radionuclides from water by means of bioaccumulation by using biologically activated carbon and blue-green algae found that the fixation by algae is more efficient than the BAC (Miskovic et al 1992).

4.6 COST AND AVAILABILITY OF SELECTED TECHNOLOGIES

A study of the Los Alamos Environmental Restoration and Waste Management Five-Year Plan Task Description Document gives a breakdown of costs for treatment of low-level radioactive liquid waste (LLRLW). On a yearly basis, treatment plant operations for the treatment of 2 million liters of LLRLW per month are estimated at \$1.33 million. This works out to roughly \$210 per thousand gallons. Add to this the cost of wastewater collection, instrumentation and other routine maintenance, and the cost is \$3.26 million. The costs of complying with NPDES permits, safety requirements and administration add roughly \$350,000.

In the case of the Savannah River treatment facility, a 165 gpm capacity plant treats approximately 20 to 25 million gallons yearly of process water containing organics and radionuclides. The combination of treatment processes include microfiltration, GAC, IX, and RO. Direct operating costs range from \$18 to \$20 million per year. At the high end, this is \$1,000 per thousand gallons.

The remediation of the aquifer at the Bison Basin uranium mine processed a total of 114 million gallons of groundwater through reverse osmosis and ion exchange processes. The cost of equipment was about \$250,000, and direct operating costs during the ten month operation was \$706,800. This works out to an O&M cost of \$6.20 per thousand gallons.

Osmonics prepared conceptual cost estimates for systems featuring reverse osmosis at 100 gpm, 250 gpm, 500 gpm, and 1000 gpm. Unit processes for these systems include prechlorination, multi-media green sand filtration, dechlorination, 5 micron microfiltration, pH adjustment, reverse osmosis, and a clean-in-place backwash system for the RO units. Capital costs range from \$125,000 to \$875,000 as shown in Appendix B.

Goble-Sampson, Inc. provided conceptual capital cost estimates for coagulation/clarification unit processes for 100 gpm, 250 gpm, 500 gpm, and 1000 gpm. Costs range from \$56,000 to \$220,000 (delivered) for the treatment units and are shown in Appendix B. These package systems include a chemical feed system, flocculator, tube settler, and clarifier.

All of the technologies recommended for potential implementation and shown on the three schematic diagrams are currently available. Estimated costs for filtration and reverse osmosis equipment and corresponding operating costs are given in Appendix B. Estimated costs for a full-scale, high-volume treatment system (e.g., Figure 7) are based on system costs (rather than individual unit process costs) developed by EPA. These costs are shown in Appendix B.

Comparison of different technologies may have less to do with the actual costs of the removal technology than the final disposition of wastes. For this reason, the Hanford facility is attempting to "delist" their effluent with the EPA to allow for disposal as a non-hazardous waste. This is particularly true for the disposal of "mixed wastes" effluent which contain both radionuclides and other hazardous materials. There are currently few disposal options for such wastes. By demonstrating that the effluent from the treatment process no longer has the characteristics of a hazardous waste under 40 CFR Part 261, subpart A, a great savings in costs may be realized.

Cost information for emerging technologies is minimal. There are several scenarios that cause this lack of data. Many of these projects are not yet fully operational or treatability tests have just recently been performed and reliable cost data is not yet available. In the case of proprietary or processes vendor-supplied information, there is an economic incentive to keep costs competitive such that reported costs may or may not reflect the actual cost of implementing a system. The final difficulty is in the scaling of costs from a bench scale process to a pilot- or

full-scale process. In the Filter-Flow Technology CFPM process, a 5-gallon bench test was performed. Cost data for this process cannot reasonably be extended to imply scaled up costs.

TABLE 16
SUMMARY OF RADIONUCLIDE REMOVAL PERFORMANCE DATA
FOR OPERATING WATER TREATMENT SYSTEMS

Facility	Media	Pretreatment Unit Processes	Polishing Processes	Target Analyte	Reported Influent Concentration	Reported Effluent Concentration	Reported Removal Efficiency
Denver Water Board (Lauer 1988)	Wastewater	Lime Clarification	Granular Activated Carbon/Reverse Osmosis	Uranium	0.008 - 0.017 mg/L (12-25 pCi/L)	Below Detection Limit	79.8%
				Gross Alpha	3.6 pCi/L		
				Gross Beta	6.5 pCi/L		
Jefferson County Colorado School District (Jelinek and Sorg 1988)	Groundwater	Microfiltration	Anion Ion Exchange	Uranium	110.0 µg/L (165 pCi/L)	0.2 µg/L (3 pCi/L)	99.8%
Bison Basin Mine (Catchpole et al. 1991)	Groundwater	Ion Exchange/ Sand Filtration	Reverse Osmosis	Gross Alpha	34±5 - 68±9 pCi/L	2±1 - 3±1 pCi/L	85%-94%
Homestake Mining Company (Cellan 1994)	Groundwater	Ion Exchange	Reverse Osmosis	Uranium	25 mg/L (37,500 pCi/L)	0.4 mg/L (600 pCi/L)	99.8%
UMETCO Gas Hills, WY (Hoffman 1994)	Groundwater	Sand Filtration/ Ion Exchange	Reverse Osmosis	Uranium	22-25 mg/L (33,000-37,000 pCi/L)	0.02-0.07 mg/L (30-105 pCi/L)	>99%
Rocky Flats-OU1 (Cirillo 1994)	Groundwater	Ion Exchange	Ion Exchange	Strontium	NA	NA	99%
				Uranium	7 pCi/L	0.074 pCi/L	98.9%
Rocky Flats-OU2 (DOE 1993b)		Neutralization/ Chemical Precipitation	Membrane Filtration	Gross Alpha	5-10 pCi/L	NA	67.8%
				Uranium	5-10 pCi/L	NA	81.1%

TABLE 16
SUMMARY OF CURRENT WATER TREATMENT PROCESSES
RADIONUCLIDE REMOVAL
(continued)

Facility	Media	Pretreatment Unit Processes	Polishing Processes	Target Analyte	Reported Influent Concentration	Reported Effluent Concentration	Reported Removal Efficiency
Hanford - 200 Area (Garrett 1990)	Purge water from well	Reverse Osmosis	Ultrafine Filtration	Gross Alpha	1.94 pCi/L	0.25 pCi/L	87.6%
				Gross Beta	5.91 pCi/L	0.70 pCi/L	88.2%
				Uranium	2.58 pCi/L	0.45 pCi/L	82.5%
Hanford - 200 Area (Garrett 1990)	Groundwater	Reverse Osmosis	Ultrafine Filtration	Uranium	4700 pCi/L	4.7 pCi/L	99.9%
Savannah River (Diener 1994)	Waste Stream	pH Adjustment/ Flocculation	Pressure Ultra Filtration 0.3 micron (nominal)	Uranium	50 ppm (75,000 pCi/L)	10 ppb (15 pCi/L)	>99%
Los Alamos National Laboratory (Moss 1994)	Treated Wastewater	Coagulation/ Clarification/ Gravity Filter	Ion Exchange (Selective)	Uranium Plutonium Americium	100 nCi/L (100,000 pCi/L)	100 pCi/L	99.9%
Millstone 2 - Northeast Nuclear Energy Company (Pfeiffer 1994)	Reactor Steam Letdown	Demineralizer and 0.45 micron absolute filter	Downstream Post Filter 0.45 µm (absolute)	Cobalt-58	1×10^{-4} µCi/ml (100,000) pCi/L	1×10^{-6} µCi/ml (1,000 pCi/L)	*varies as filter ages
Obrigheim (Weber et. al. 1989)	Reactor Steam Letdown	Demineralizer and 0.45 micron absolute filter	Postfilter 0.2 µm (absolute)	Cobalt-58	Steady State 270×10^{-7} µCi/ml (27,000 pCi/L)	0.5×10^{-7} µCi/ml (500 pCi/L)	99.8%
Obrigheim (Weber et. al. 1989)	Reactor Steam Letdown	Demineralizer and 0.45 micron absolute filter	Postfilter 0.2 µm (absolute)	Cobalt-58	Start-up 5500×10^{-7} µCi/ml (550,000 pCi/L)	200×10^{-7} µCi/ml (20,000 pCi/L)	96.4%
Callaway Station - Union Electric (Weber et. al. 1989)	Reactor Steam Letdown	Demineralizer	Post Filter 6.0 µm (absolute)	Cobalt-58	Steady State $10,000 \times 10^{-7}$ µCi/ml (1 x 10 ⁶ pCi/L)	10×10^{-7} µCi/ml (1,000 pCi/L)	99.9%

TABLE 16
SUMMARY OF CURRENT WATER TREATMENT PROCESSES
RADIONUCLIDE REMOVAL
 (continued)

Facility	Media	Pretreatment Unit Processes	Polishing Processes	Target Analyte	Reported Influent Concentration	Reported Effluent Concentration	Reported Removal Efficiency
Callaway Station - Union Electric (Weber et. al. 1989)	Reactor Steam Letdown	Demineralizer	Post Filter 6.0 μ m (absolute) and then 0.45 μ m (absolute)	Cobalt-58	Start-up 76,570x10 ⁻⁷ μ Ci/ml (7.657x10 ⁶ pCi/L)	271x10 ⁻⁷ μ Ci/ml (27,100 pCi/L)	99.6%

NA - Not Available

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TABLE 17
SUMMARY OF RESEARCH ON EMERGING TECHNOLOGIES
FOR RADIONUCLIDE REMOVAL

Location	Scale	Unit Process	Target Analyte	Reported Influent Concentration	Reported Effluent Concentration	Reported Removal Efficiency
Rocky Flats OU4 (DOE 1994a)	Pilot	Colloid Filter Polishing Method	Uranium-238	3.3+0.82 pCi/L	-0.01+0.03 pCi/L	>99%
			Uranium-234	5.1+1.1 pCi/L	-0.01+0.03 pCi/L	>99%
			Plutonium-239	6.1+1.0 pCi/L	-0.01+0.02 pCi/L	>99%
			Americium-241	9.2+2.4 pCi/L	0.05+0.04 pCi/L	>99%
			Gross alpha	46+8 pCi/L	14+3 pCi/L	37.7%*
Rocky Flats (EG&G 1993)		Particulate Filtration/Granular Activated Carbon	Gross beta	35+8 pCi/L	31+5 pCi/L	31.1%*
			Plutonium	NA	NA	30%
Nuclear Power Plant (Weber 1989)	Pilot	Positive Zeta Potential Ultrafine Filters	Cobalt-58	1.1x10 ⁻² µCi/mL (1.1x10 ⁷ pCi/L)	5X10 ⁻⁷ µCi/mL (500 pCi/L)	99%
Fernald Environmental Management Project (Potts and Churchwell 1994)	Bench	Ferrate Potassium Precipitation/ Coprecipitation	Uranium	62-490 µg/L (93-735 pCi/L)	40 pCi/L NA	94%
			Radium Uranium	25 pCi/L 180 pCi/L	1 pCi/l 30 pCi/l	
Chimney Hill, Texas (Clifford and Zhang)		Ion Exchange Mixed Bed	Americium Plutonium	10 ⁻⁷ g/L (3.4x10 ⁵ pCi/L) 10 ⁻⁴ g/L (6.22x10 ⁶ pCi/L)	NA	98.4%-99.8%
Rocky Flats (DOE 1989)	Bench	Magnetic Filtration	Plutonium	10 ⁻⁴ g/L (6.22x10 ⁶ pCi/L)	10 ⁻³ g/L (622 pCi/L)	
Rocky Flats (DOE 1985)	Bench	Ferrite Precipitation/ Coprecipitation				

TABLE 17
SUMMARY OF RESEARCH ON EMERGING TECHNOLOGIES
FOR RADIONUCLIDE REMOVAL
(continued)

Location	Scale	Unit Process	Target Analyte	Reported Influent Concentration	Reported Effluent Concentration	Reported Removal Efficiency
Rocky Flats (DOE 1994a)	Bench	Adsorbants SORBPLUS and Granular Activated Alumina	Uranium	3.1 mg/L (4,650 pCi/L)	NA	99%
Undisclosed DOE site (Potts and Churchwell 1994)	Bench	Potassium Ferrate (TRU/clear) Precipitation/Coprecipitation	Americium Plutonium	37,000 pCi/L (total activity)	40 pCi/L (total activity)	>99%
Savannah River (Bibler 1994)	Pilot	Mag-Sep®	Heavy Metals	NA	NA	NA
Rocky Flats-002 (DOE 1993b)	Pilot	chemical Precipitation/Filtration	Gross Alpha Uranium	5-10 pCi/L	NA	NA
Los Alamos	Bench	Ultrafiltration Spintex®	Americium	NA	NA	NA

* - Average Removal Efficiencies
NA - Not Available

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL CONCLUSIONS

Ion exchange, reverse osmosis, coagulation-filtration, and lime softening are the most common technologies studied for the removal of radionuclides from water and wastewater. These technologies are defined Best Available Technologies (BATs) for removal of radionuclides from drinking water supplies. The available research shows that full scale treatment facilities using current BATs can achieve removal efficiencies over 99 percent for naturally occurring radioactive materials (Tables 4, 5, 6, and 7) over a broad range of influent concentrations. For plutonium and americium, high removal efficiencies (e.g., >99%) are almost exclusively derived from laboratory ("bench scale") tests and/or start with such high influent radio-activity levels (>10,000 pCi/L), that no conclusions regarding removal efficiencies at picocurie and sub picocurie influent activity levels can be made at this time.

The ability to maintain high removal efficiencies at high flow rates and low influent concentrations has not been reliably demonstrated. In addition, bench tests generally focussed on one or two specific radionuclides, and removal of multiple radionuclides is less well established. Full scale performance will likely be significantly poorer than laboratory results because factors that exhibit variability in the "real world" are carefully controlled in the laboratory. These variability factors (e.g., temperature, pH, TDS, flow rate, and the presence of other contaminants) should be carefully considered, and additional pilot studies should be conducted before extrapolating laboratory test results to full scale operations.

Conventional water and wastewater treatment processes such as coagulation/flocculation, adsorption, and chemical precipitation, followed by filtration, have been proven effective in removing high to medium levels of all radionuclides. Application of these conventional technologies to removal of picocurie and sub-picocurie levels of mixed radionuclides has shown mixed results on a production scale. New adsorption media such as bone char and Filter Flow 1000™ have undergone considerable research and appear very promising. The main drawback to conventional processes is that they have significant waste disposal considerations and high capital and operating costs.

Reverse osmosis, ion exchange, and evaporation processes also have high capital and operating cost, however they do provide more reliable low level radionuclide removal. Ion exchange has proven effective for uranium and radium removal but is generally designed for selected removal of specific contaminants. Specialized resins which specifically target low levels of plutonium and americium in the environment have not been proven, although laboratory tests of existing resins such as Duolite GT-73 and Amberlite IRC-718 (both from Rohm and Haas) have potential application. Ultrafiltration and reverse osmosis have the advantage of providing non-selective removal of all suspended or colloidal contaminants down to the specified rating of the filter or membrane. What isn't known, definitively, is the particle size range at which operations personnel can confidently expect radionuclides to occur, or more precisely, what level of filtration will always be effective for low level radionuclide removal. Evaporation is also non-selective, and removes virtually 100 percent of non-volatile radionuclides, but is not economical for dilute waste streams.

A comparison of required removal efficiencies from Table 5, to achievable removal efficiencies for specific BATs from Tables 6 to 14, is shown in Table 18. Conclusions that can be drawn from this comparison are as follows:

1. Lime softening can achieve SDWA MCLs and the more stringent site-specific state water quality standards for radium and uranium (for the assumed maximum influent concentrations), but insufficient data exists to reliably predict removal efficiencies for other constituents.
2. Coagulation/filtration can achieve MCLs for all constituents except gross beta. Coagulation/filtration can potentially achieve site-specific water quality standards for all constituents except gross beta, however, achieving site-specific gross alpha, plutonium, and americium standards requires performance at the very upper end of the demonstrated efficiency ranges.
3. Ion exchange (preceded by suspended solids removal) can achieve MCLs and site-specific state water quality standards for uranium and radium, and can probably achieve MCLs and site-specific standards for gross alpha and gross beta. Effective removal of gross alpha and gross beta activity by ion exchange is achievable assuming constituents are in dissolved or ionic form and proper selection of exchange resin(s) to match the primary contributors to general gross alpha/gross beta activity is made.

TABLE 18
COMPARISON OF REMOVAL EFFICIENCIES REQUIRED TO MEET
STANDARDS TO DOCUMENTED REMOVAL EFFICIENCIES OF BAT

Contaminant	Standard (pCi/L)		Required Removal Efficiency ² (%) to Meet:		Documented Range of Removal Efficiencies			
	MCL ¹	WQCC Standard	MCL	WQCC	Coagulation/ Filtration	Lime Softening	Ion Exchange	Reverse Osmosis
Americium-241	-	.05	50	> 99	76-99.9	*	*	*
Plutonium-239, -240	-	.05	50	98.1	59-99.9	*	*	*
Radium-226	20	5	-	75	25-90	75-95	80-99	87-98
Uranium-238	30	5	-	76	57-95	85-99	35-99.9	98-99.5
Gross Alpha	15	7	80	91	48-86	*	88-99	96-99.9
Gross Beta	4 mrem/yr	5	90.5	97.6	11-55	*	70-99	96-99.9

* Insufficient data.

¹Listed MCL is the most stringent of current or proposed MCLs.

²Required removal efficiency based on maximum calculated concentrations from Table 5.

³Documented range of removal efficiencies from Tables 6-14.

⁴Reported removal efficiencies are not necessarily in the same concentration/activity range.

4. Ion exchange resins for selective removal of plutonium and/or americium in an environmental application are unproven. Comparative studies of the removal efficiencies of existing resins against various adsorbents, such as bone char, indicate that adsorbents will likely be cheaper and more efficient than resins in achieving low level plutonium and americium removal.
5. Reverse osmosis (preceded by suspended solids removal) can achieve MCLs and the more stringent site-specific water quality standards for all radionuclides and combinations of radionuclides including plutonium and americium. Tight control of influent suspended solids and regular cleaning of reverse osmosis membranes is imperative.

Evaporation technology is not a defined BAT, but can also achieve site-specific water quality standards for all radionuclides. However, application of this technology to large volumes of stormwater is economically impractical. Another technology not specifically listed as a BAT is microfiltration/ultrafiltration, because this technology by itself cannot achieve the stringent site-specific water quality standards at maximum assumed activity levels.. At lower assumed activity, microfiltration/ultrafiltration non-selectively removes all types of radioactive constituents and is a viable and inexpensive alternative treatment technology.

Technologies that show the most promise for adapting to routine operating procedures for transuranic removal are technologies currently in existence which can be modified or adjusted for specific application to particular radionuclides. These include improvements in filtration technology (both media and fabric type filters), improved ultrafiltration and reverse osmosis membranes, improved or specialized flocculants and adsorbents, and development of specialized ion exchange resins.

There are no established BATs for the removal of low levels of transuranic radionuclides. Conventional wisdom concerning the most promising technologies is based on several laboratory-scale and a few pilot-scale tests. For these reasons, it should be anticipated that any plan for large-scale removal of radionuclides will undergo a number of changes in design and operating procedures before optimal treatment is achieved.

5.2 SCREENING AND SELECTION OF UNIT PROCESSES

Table 19 presents the results of the technology screening and selection process described in Chapter 3. Each of the technologies (unit processes) discussed in Chapter 4 (as well as other processes used for pretreatment or post treatment) are evaluated for potential application at RFETS. In general, unit processes or technologies classified as emerging were rejected from consideration since they could not be implemented without first developing them further for commercial application.

Of the technologies remaining after initial screening, comparative evaluation for cost, implementability, and waste impacts, led to selection of coagulation/precipitation, adsorption, ultrafiltration, and reverse osmosis as the recommended technologies for removing transuranics from water. The application of each of these technologies, either separately or in conjunction with each other, and the system arrangement required, depends on the concentrations and mixtures of radionuclides requiring treatment, and on required flow rates.

Assuming low to moderate influent activity levels consistent with the calculated maximums of Table 5, and low to moderate required flow rates, ultrafiltration and reverse osmosis are the recommended treatment processes. Filtration advances, portability, and low initial capital costs, combined with a low expected frequency of use, make these technologies the most cost effective option. These technologies also generate the least amount of waste and can be implemented more quickly than other options. For higher flow rates and activity levels, reverse osmosis provides greater removal capabilities than ultrafiltration alone, and has the distinct advantage of providing non-selective removal of multiple radionuclides, alleviating the need for designing contaminant-specific removal processes. Both of these processes also offer built-in versatility, in that they can be designed for portable or stationary use and can be operated in parallel to achieve higher flow rates.

Based on low expected influent radionuclide concentrations, high costs, and significant waste generation impacts, capital expenditures for a full scale treatment plant appear unwarranted, and near term implementation of a full scale treatment system is not recommended. If implemented in the future, a full-scale treatment facility should build upon the aforementioned ultrafiltration and reverse osmosis processes, by adding conventional coagulation/precipitation processes as pretreatment steps and adding adsorption processes for final polish, if needed.

TABLE 19
RESULTS OF SCREENING AND SELECTION
PROCESS FOR RADIONUCLIDE REMOVAL TECHNOLOGIES

SCREENING CRITERIA		COMPARATIVE CRITERIA						
Technology or Unit Process	Applicable to Low Level Radionuclides at RFETS?	Contributes to Overall Treatment Strategy?	Demonstrated technology, not necessarily for radionuclides?	Equipment and Materials Readily Available?	Cost	Implementation Difficulties	Adverse Waste Impacts	Comments
Sand and Multimedia Filtration	Yes	Yes	Yes	Yes	Low	Low	Medium	Standard Pretreatment Technology
Iron and Alum Coagulation/Flocculation	Yes	Yes	Yes	Yes	Medium	Medium	High	Standard Pretreatment Technology Removes Course Fraction Particulates. Generates High Sludge Volume.
Lime Softening (Hydroxide Precipitation)	Yes	Yes	Yes	Yes	Medium	Medium	High	Standard Precipitation Process. Generates High Sludge Volume
Sulfide/Sulfate Precipitation	Yes	Yes	Yes	Yes	Medium	Medium	High	Standard Precipitation Process. Generates High Sludge Volume
Ferrite Precipitation/Coprecipitation	Yes	Yes	Yes	Yes	Medium	Medium	Medium	Not demonstrated at production scale for radionuclides
Potassium Ferrate Precipitation/Coprecipitation	Yes	Yes	Yes	Yes	Medium	Medium	High	Emerging Precipitation Process. Generates High Sludge Volume

TABLE 19
RESULTS OF SCREENING AND ELECTION
PROCESS FOR RADIONUCLIDE REMOVAL TECHNOLOGIES
(continued)

SCREENING CRITERIA					COMPARATIVE CRITERIA			
Technology or Unit Process	Applicable to Low Level Radionuclides at RFETS?	Contributes to Overall Treatment Strategy?	Demonstrated technology, not necessarily for radionuclides?	Equipment and Materials Readily Available?	Cost	Implementation Difficulties	Adverse Waste Impacts	Comments
Ion Exchange	Yes	Yes	Yes	Yes	High	Low	High	BAT for Uranium and Radium. Not Demonstrated for Pu and Am.
Activated Carbon Adsorption	No	Yes	Yes	Yes				High Probability of Generating mixed waste.
Colloid Filter Polishing Method(Proprietary RHM 1000™ adsorption	Yes	Yes	No	Unknown				Emerging Technology. Bench and Pilot Tests encouraging.
Sorbplus™ Adsorption	Yes	Yes	Yes	Yes	Medium	Medium	High	Not demonstrated at production scale for radionuclides.
Activated Alumina Adsorption	Yes	Yes	Yes	Yes	Medium	Medium	High	Not demonstrated at production scale for radionuclides.
Bone Char Adsorption	Yes	Yes	No	Unknown				Emerging Technology. Bench Tests encouraging. More research needed.
Metal Recovery Agent (MRA) Adsorption	Yes	Yes	No	Yes				Stringent pH control required.

TABLE 19
RESULTS OF SCREENING AND ELECTION
PROCESS FOR RADIONUCLIDE REMOVAL TECHNOLOGIES
(continued)

SCREENING CRITERIA					COMPARATIVE CRITERIA			
Technology or Unit Process	Applicable to Low Level Radionuclides at RFETS?	Contributes to Overall Treatment Strategy?	Demonstrated technology, not necessarily for radionuclides?	Equipment and Materials Readily Available?	Cost	Implementa-tion Difficul-ties	Adverse Waste Impacts	Comments
Magnetic Filtration	Yes	Yes	No	Yes				Emerging Technology. Bench Tests encouraging. More research needed.
Microfiltration	Yes	Yes	Yes	Yes	Low	Low	Medium	High Operating Costs
Ultrafiltration (Backwashable)	Yes	Yes	Yes	Yes	Medium	Low	Low	Waste stream requires additional treatment. Recommended Technology.
Reverse Osmosis	Yes	Yes	Yes	Yes	High	Low	Low	BAT for alpha emitters. Recommended Technology
Biological Processes	Unknown	Yes	Yes	No				Efficiency of biological processes for radionuclides is unknown.
Evaporation	Yes	Yes	Yes	Yes	High	High	Low	Potential Technology for treatment of waste streams from other unit processes
Thin Film Dryer	Yes	Yes	Yes	Yes	High	High	Medium	Same as above
Filter Press	Yes	Yes	Yes	Yes	Medium	Medium	High	Same as above

5.3 PROCESS DIAGRAMS AND SYSTEM CONFIGURATIONS

Figures 5, 6, and 7 present three conceptual treatment system schematics. They are arranged in order of complexity, and also represent increasing capital costs and increasing time frames for implementation. Recognizing that stormwater will occasionally have high turbidity, and will periodically experience significant algal blooms, all treatment systems shown in the schematics include some type of pretreatment for suspended solids and organic matter before water can be treated for radionuclides.

The schematics are presented as low flow, intermediate flow, and high flow and are designed to support different treatment scenarios.

5.3.1 Low Flow - Staged Sub-micron Filtration

This system consists entirely of increasing levels of filtration, and assumes that influent concentrations are low enough that a system removal efficiency of 75 percent will meet imposed site specific water quality standards. It was also assumed that the extent of contamination was small enough in volume, or suitably isolated, such that a 50 gpm system was adequate for operational needs. Primary filtration by deep bed sand or multimedia filtration will remove coarse suspended sediment to approximately 20 microns (nominal). This unit process is followed by cartridge or bag type microfilters to remove remaining suspended particles (and some radioactivity) down to approximately 5 microns absolute. Backwashable ultrafilters to 0.2 micron absolute rating will remove sufficient colloidal fraction radioactivity to achieve standards.

Waste streams include sand filter backwash, disposable filter bags or cartridges and ultrafilter backwash. Assuming defined hazardous waste constituents are not present, sand filter and ultrafilter backwash can be combined and settled in a separate tank with water recycled back to the sand filter. Bag or cartridge filters are disposable as radioactive waste. Ultrafilters should have long life. Settled solids from filter backwash can be further dewatered in an evaporator or thin film dryer and then drummed and disposed of as a low level waste. No added materials (flocculents, coagulants) are needed. Operating costs for labor and disposable materials are moderate to high, however, capital costs are low.

5.3.2 Intermediate Flow - Staged Sub-Micron Filtration and Reverse Osmosis

This system utilizes primary deep bed sand filtration, followed by microfiltration and ultrafiltration to approximately 0.20 micron absolute, similar to the low flow system, followed by reverse osmosis. For this system, higher influent activity levels were assumed, such that a system removal efficiency of 95 percent is required to achieve standards. Additional or larger equipment provides for greater flow rate. Similar to the low flow system, sand filtration will remove coarse suspended particles and decrease loading on subsequent unit processes. Unlike the low flow system, the arrangement of the backwashable and disposable filters are reversed. In this system, placing a backwashable 5 micron microfilter ahead of a disposable 0.2 micron ultrafilter provides greater service life to the ultrafilters and reverse osmosis membranes, thereby improving both the efficiency and economics of the system.

Ultrafiltration and reverse osmosis will selectively remove all radionuclides in the colloidal fraction in which research indicates the majority of remaining radioactivity exists after suspended solids removal. Sidestreams resulting from this treatment system include:

1. Sand filter backwash water;
2. Microfiltration - backwash water;
3. Ultrafiltration spent cartridges; and
4. Reverse Osmosis brine.

Sand filter backwash water can be settled and returned to the influent side of the system, or can be hauled as a liquid to the on-site wastewater treatment plant once that sidestream has been characterized for radioactivity or hazardous constituents. Spent ultrafiltration cartridges should be disposed of as a low level radioactive waste. Sidestreams of both microfiltration backwash water and reverse osmosis brine can be combined for dewatering in an evaporator. The resultant solids should be drummed and disposed of as a low level waste.

5.3.3 High Flow - Full Scale Treatment

Construction of a full scale treatment system is not recommended. However, the suggested approach, given below and diagrammed on Figures 7a and 7b, for long-term, continuous low

level transuranic removal from water, is based on the literature review and the known aqueous chemistry of uranium, plutonium, and americium. It should be regarded as a reasonable first approach that will undoubtedly require modification and fine tuning if implemented. The treatment system should be constructed to allow for experimentation with quantities and types of additives and filters. The treatment system and treatment strategy described below assume the highest contamination levels and correspondingly highest flow rates. Assumed influent concentrations require a system efficiency of 99 percent to achieve site specific water quality standards.

Treatment Strategy

In water, plutonium and americium are normally in solid particulate form, or electrically attached to colloidal particles, while uranium is normally in a dissolved form. The basic strategy considered here for removal is to: precipitate as much particulate and dissolved transuranic activity as possible by adding precipitating agents and flocculants, allow to settle, filter remaining suspended solids, treat water passing the filters by ion exchange, adsorbing columns, and/or reverse osmosis to remove remaining activity, and finally, if needed, pass the treated water through additional adsorbing columns for polishing.

Treatment Steps

1. Adjust pH and oxidation potential to the optimum values for precipitating dissolved radionuclides. Precipitating agents such as carbonate or sulfide might be needed. Coprecipitation with ferrite or ferrate formed *in situ* is particularly attractive based on laboratory experiments.
2. Flocculants and coagulants are added to help settle out the fine particles:
3. Several successive stages of filtration from sand to micron rated filters remove particles that did not settle.
4. Chemical adjustment of pH, hardness, etc. prior to treatment by ion exchange, adsorbing columns, or reverse osmosis.
5. Treatment by ion exchange, adsorbing columns, or reverse osmosis. Multiple units may be operated in parallel to achieve required flow rates.

6. If additional finishing is required, adsorption on activated alumina, bone char, or GAC can be the last step. Used in this way, final adsorption units should have long lives and present minimal disposal volumes.

Sidestreams are to be handled in a manner similar to those in the intermediate scheme. Added sidestreams, chemical sludge from the clarifier, ion exchange regenerate, and absorbent column backwash water would also be evaporated and solidified.

5.4 RECOMMENDATIONS FOR FUTURE RESEARCH

There are numerous treatability studies ongoing or planned within the DOE Complex which are investigating specialized chemical processes, proprietary adsorption or filtration media, and advances in ion exchange technology. It is recommended that these treatability studies be completed and evaluated before pursuing additional research in these areas.

The type of research that appears to be most lacking at this time is research on simple, cost effective improvements to existing technologies that address very low influent concentrations of mixed radionuclides. Three technologies that meet these goals and warrant additional research are (1) magnetically assisted filtration, (2) environmental applications of absolute rated filters, and (3) adsorption with bone char.

Magnetically assisted filtration has the potential to use common, locally available material (ferrite or magnetite), conventional filtration equipment, and well known principles of electromagnetism to enhance removal of radionuclides at low concentrations. Current research with cartridge filters and coated sand filtration media both show that positive electrical potentials on the surfaces of the filtration media enhance filtration effectiveness of colloidal and dissolved materials. This is due to the fact that many fine particles in aqueous systems possess a net negative surface potential. By applying these principles to the specific application of removing low level radionuclides from relatively clean stormwater, it may be possible to achieve stringent discharge standards without generating significant waste streams.

Additional studies of speciation and particle size distributions of plutonium, americium, uranium, and other radionuclides occurring in natural systems is also recommended. A better understanding of the particle size ranges that contain the highest percentages of these radioactive constituents will determine whether new or improved absolute rated filters are capable of avoiding

the cost of more advanced technologies such as reverse osmosis and ion exchange in removing mixed radionuclides to a level adequate to meet standards.

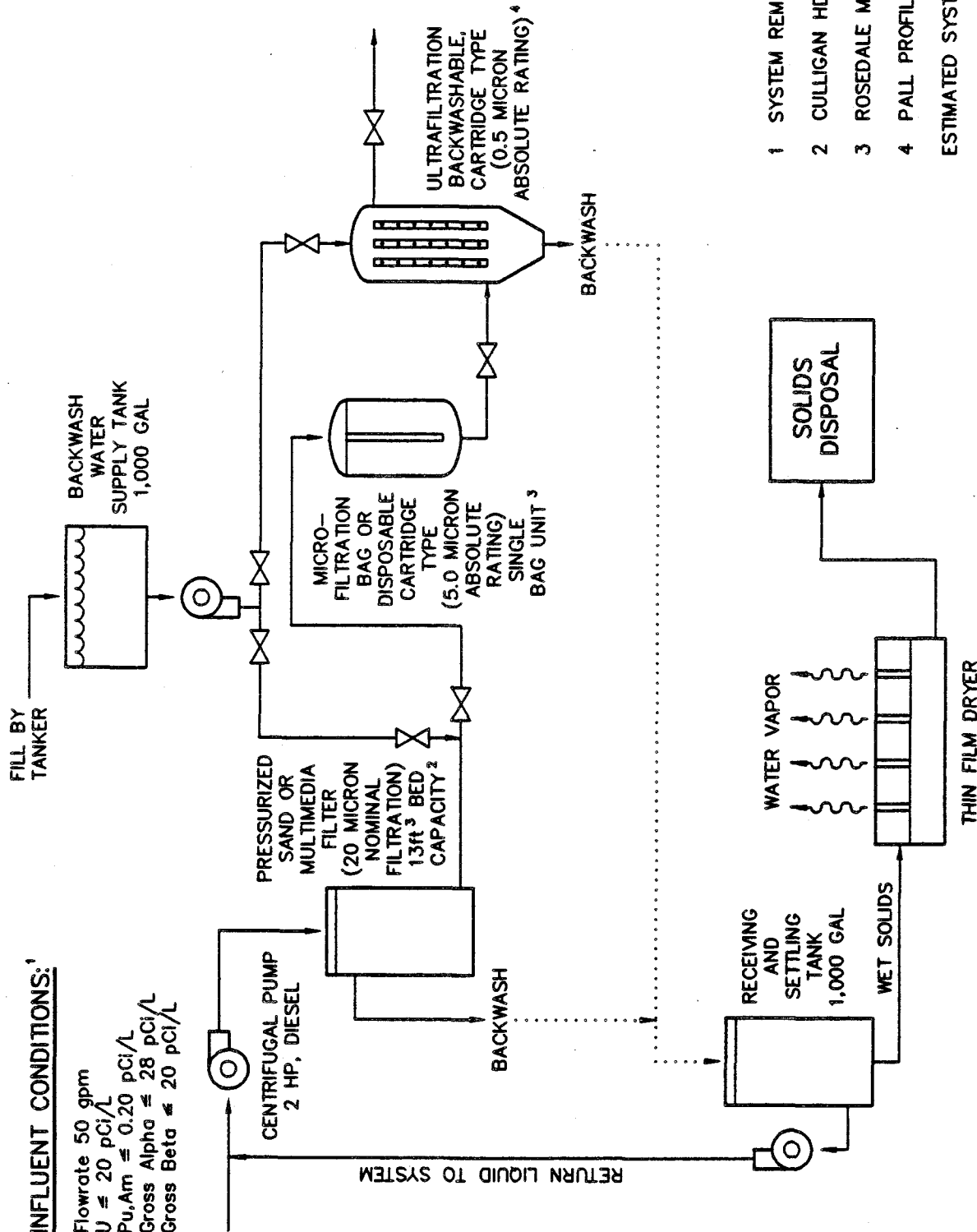
Further study of bone char as a plutonium and americium specific adsorbent are also recommended. The excellent results of preliminary testing, coupled with the fact that the raw material for bone char (e.g., bone) will be both inexpensive and readily available, make this technology very attractive. It may be possible to substitute bone char for more expensive materials in conventional absorption processes and simultaneously achieve greater removal efficiencies. Conversely, bone char adsorption columns may be an inexpensive replacement for IX or RO as a final polishing step prior to discharge.

INFLUENT CONDITIONS:¹

Flowrate 50 gpm
 $U \leq 20$ pCi/L
 $Pu, Am \leq 0.20$ pCi/L
 Gross Alpha ≤ 28 pCi/L
 Gross Beta ≤ 20 pCi/L

EFFLUENT CONDITIONS:¹

$U < 5$ pCi/L
 $Pu, Am < 0.05$ pCi/L
 Gross Alpha < 7 pCi/L
 Gross Beta < 5 pCi/L



- 1 SYSTEM REMOVAL EFFICIENCY = 75%
 - 2 CULLIGAN HD-30
 - 3 ROSEDALE MODEL 6
 - 4 PALL PROFILE II, 005
- ESTIMATED SYSTEM COST: \$100-\$150K

WRIGHT WATER ENGINEERS, INC.
 2490 W. 26TH AVE. SUITE 100A
 DENVER, CO 80211
 (303)480-1700

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 CHECK _____ EMM
 DATE 11/10/94
 JOB NO. 901-004.460

FIGURE 5
CONCEPTUAL TREATMENT SCHEMATIC
FOR RADIONUCLIDE REMOVAL
LOW FLOW SYSTEM
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

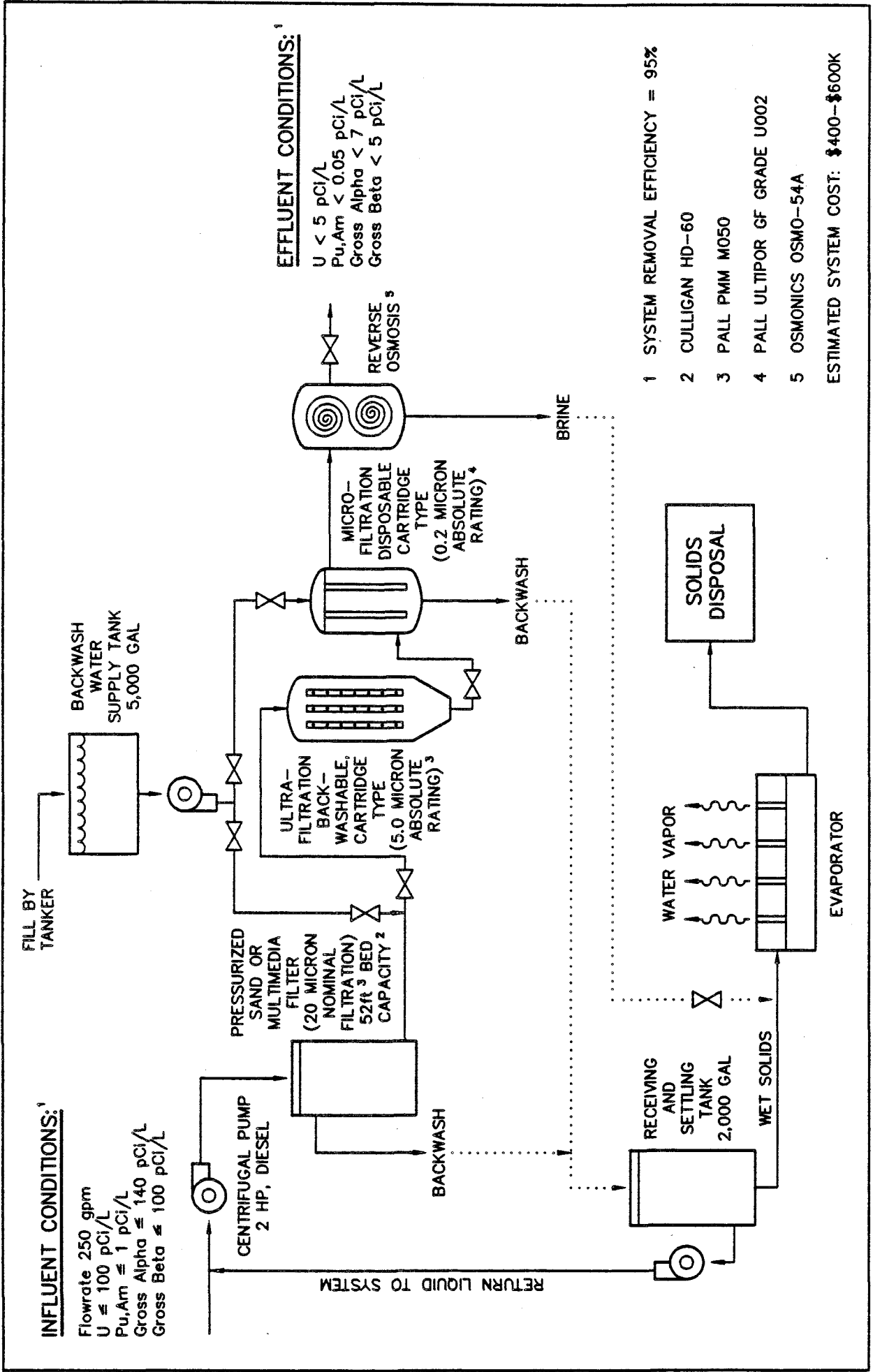


FIGURE 6
**CONCEPTUAL TREATMENT SCHEMATIC
 FOR RADIONUCLIDE REMOVAL
 INTERMEDIATE FLOW SYSTEM
 ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE**

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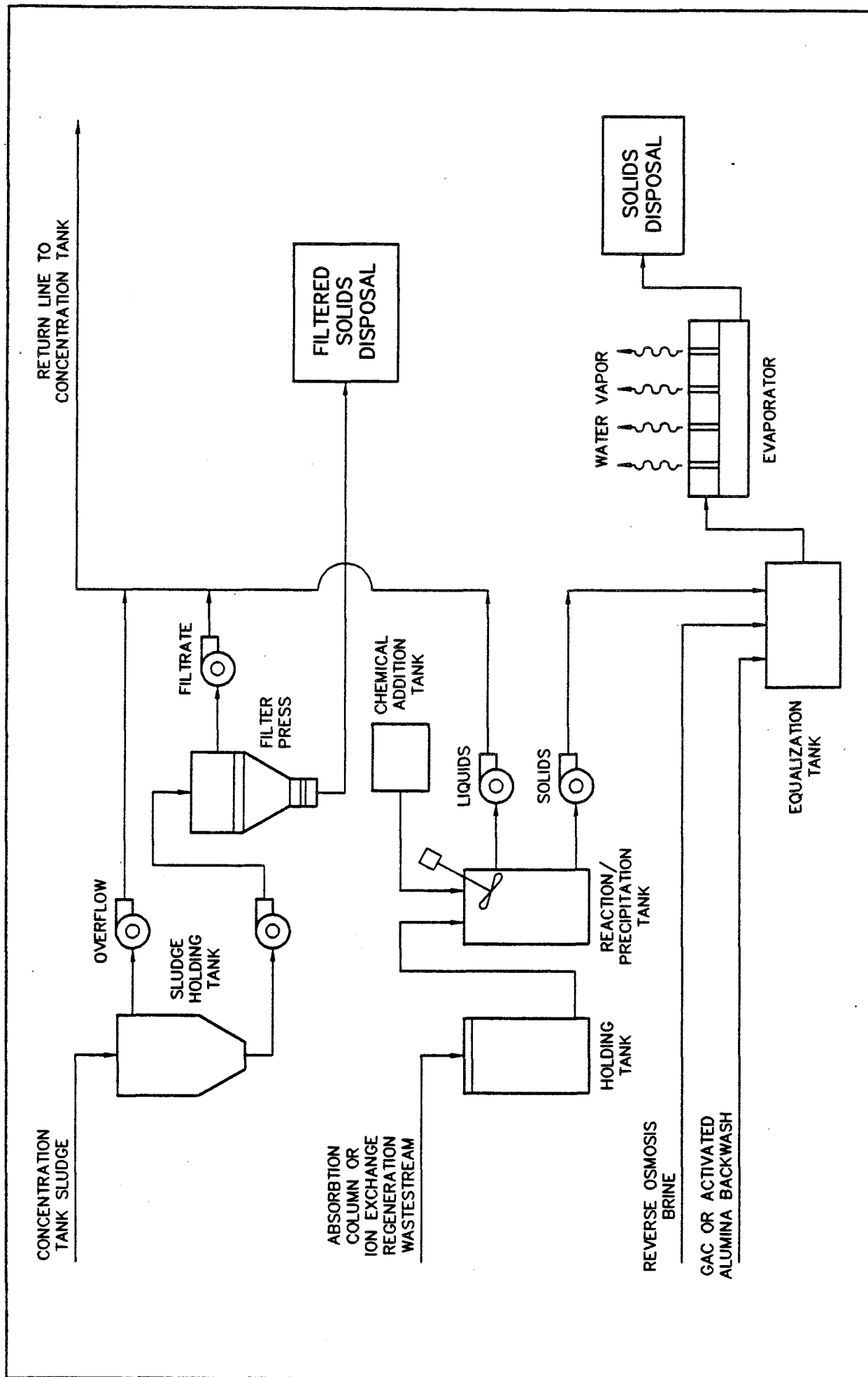


FIGURE 7b
CONCEPTUAL TREATMENT SCHEMATIC
FOR RADIONUCLIDE REMOVAL
FULL SCALE SYSTEM - SECONDARY WASTE TREATMENT
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

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APPENDIX A

RADIATION UNITS, CONVERSIONS, AND DETECTION LIMITS

Units of Radioactivity and Absorbed Radiation

Table 1: Radioactivity Parameters

Quantity	SI units	Special SI name/symbol	Conventional name/symbol	Conversion: from conventional to SI units
Activity	s^{-1}	becquerel / Bq	curie / Ci	3.7×10^{10} Bq
Absorbed dose (specific energy; Kerma)	$J\ kg^{-1}$	gray / Gy	rad / rad	0.01 Gy
Absorbed dose rate	$J\ kg^{-1}\ s^{-1}$	gray s^{-1} / Gy s^{-1}	rad s^{-1} / rad s^{-1}	0.01 Gy s^{-1}
Dose equivalent	$J\ kg^{-1}$	sievert / Sv	rem / rem	0.01 Sv
Dose equiv. rate	$J\ kg^{-1}\ s^{-1}$	sievert s^{-1} / Sv s^{-1}	rem s^{-1} / rem s^{-1}	0.01 Sv s^{-1}
Exposure	Coul kg^{-1}		roentgen / R	2.58×10^{-4} C kg^{-1}
Exposure rate	Coul $kg^{-1}\ s^{-1}$		roentgen s^{-1} / R s^{-1}	2.58×10^{-4} C $kg^{-1}\ s^{-1}$

Table 2: Unit conversions for activity (disintegrations)

To convert from	to	Multiply by
curies / Ci	picocuries / pCi	10^{+12}
curies / Ci	microcuries / μ Ci	10^{+6}
curies / Ci	becquerels / Bq	3.7×10^{10}
curies / Ci	disintegrations per second / dps	3.7×10^{10}
picocuries / pCi	microcuries / μ Ci	10^{-6}
picocuries / pCi	millicuries / mCi	10^{-9}
picocuries / pCi	curies / Ci	10^{-12}
picocuries / pCi	becquerels	0.037
picocuries / pCi	disintegrations per second / dps	0.037
picocuries / pCi	disintegrations per minute / dpm	2.22
becquerels / Bq	curies / Ci	2.7×10^{-11}
becquerels / Bq	picocuries / pCi	27
becquerels / Bq	disintegrations per second / dps	1
disintegrations per second / dps	curies / Ci	2.7×10^{-11}
disintegrations per second / dps	picocuries / pCi	27
disintegrations per second / dps	becquerels / Bq	1

Table 3: Unit conversions for concentration (disintegrations/volume or mass)

To convert from	to	Multiply by
μ Ci/mL	pCi/L	10^{+9}
μ Ci/mL	pCi/mL	10^{+6}
μ Ci/L	pCi/mL	10^{+3}
pCi/L	μ Ci/mL	10^{-9}
pCi/mL	μ Ci/mL	10^{-6}
pCi/mL	μ Ci/L	10^{-3}

Table 4: Unit conversions that apply to dose and exposure

To convert from	to	Multiply by
gray (absorbed dose of 1 J/kg)	rad (absorbed dose of 100 erg/g)	100
gray (absorbed dose of 1 J/kg)	roentgen / R (exposure dose; 1 R = radiation dose depositing 84 erg per g of air or 93 erg per g of water)	107
rad (absorbed dose of 100 erg/g)	gray / Gy (absorbed dose of 1 J/kg)	0.01
rad (absorbed dose of 100 erg/g)	roentgen / R (exposure dose; 1 R = radiation dose depositing 84 erg per g of air or 93 erg per g of water)	1.07
rem (dose equivalent = rads x quality factor)	sievert / Sv (dose equivalent = grays x quality factor)	0.01
sieverts / Sv (dose equivalent = grays x quality factor)	rem (total absorbed dose = rads x quality factor)	100
roentgen / R (exposure dose; 1 R = radiation dose depositing 84 erg per g of air or 93 erg per g of water)	rad (absorbed dose of 100 erg/g)	0.93
roentgen / R (exposure dose; 1 R = radiation dose depositing 84 erg per g of air or 93 erg per g of water)	gray / Gy (absorbed dose of 1 J/kg)	0.0093

Table 5: Quality Factors for several types of radiation

(Also called (RBE (relative biological effectiveness) values)

Radiation	Quality Factor
X- and gamma-rays	1
beta rays and electrons	1
thermal neutrons	2
fast neutrons	10
high energy protons	10
alpha particles	20
fission fragments, heavy particles of unknown charge	20
heavy ions	20

As Table 5 indicates, 1 rad of alpha-particles absorbed causes about 20 times the biological damage as 1 rad of beta-particles, 20 rem vs. 1 rem.

Conversion between units of dose and units of activity (rems to picocuries)

There is no direct conversion factor between rems and picocuries. Rems must be calculated from rads using equations that consider the particular radionuclides present and the type and magnitude of body exposure. Colorado standards for drinking water define the assumptions to be made for such a calculation.

However, a provision is made for monitoring gross beta activity without calculating a rem value. The gross beta standard for drinking water is 4 mrem ede/yr, but a beta screening standard is set at 50 pCi/L. An analysis of the major radionuclides and a calculation of the rem value is required only if the sample gross beta activity exceeds 50 pCi/L.

Discussion of Radioactivity Measurements

There are 3 different kinds of radioactivity measurements, each serving different purposes.

1. Activity

Activity is the number of disintegrations per second in a radioactive sample. Its units are the becquerel (Bq) and the curie (Ci).

$$1 \text{ Bq} = 1 \text{ disintegration/s}$$

$$1 \text{ Ci} = 3.700 \times 10^{10} \text{ disintegrations/s}$$

The activity is a measure of the rate of nuclear disintegrations and, therefore, the half-life of the radionuclide. It does not give any information about the kinds of particles emitted or their effects in the environment.

The definition of a curie originally was based on the amount of radon in equilibrium with 1 gram of radium, but now it simply is defined as the above quantity and is independent of any experimentally determined value.

2. Absorbed dose

Absorbed dose measures the amount of energy actually deposited within the mass of a receiving body. Its units are the gray (Gy) and the rad.

$$1 \text{ Gy} = \text{an absorbed dose of } 1 \text{ J/kg}$$

$$1 \text{ rad} = \text{an absorbed dose of } 100 \text{ erg/g} = 0.01 \text{ J/kg} \quad (1 \text{ erg} = 10^{-7} \text{ J})$$

Note that there is no time period specified. Every 100 ergs absorbed per gram of mass is a 1 rad dose. Thus rads, which are a dose and not a rate, cannot be directly related to curies, which are a rate.

The number of rads *per unit time* that correspond to a curie depends on the nature of the particles emitted, their energy, and the absorbing, or stopping, power of the matter in which the particles deposit their energy.

The difference between the units of *rad* and *curie* are that the rad indicates the amount of energy absorbed by matter, while the curie indicates the number of nuclei disintegrating per second.

3. Dose equivalent

Dose equivalent measures the amount of energy that produces a certain biological effect. It is an empirical quantity that attempts to quantify the fact that the biological hazard from radiation depends on two factors: the amount of energy absorbed by tissues and the type of radiation. Its units are the sievert (Sv) and the rem.

$$\text{Sv} = \text{absorbed dose in SI units} \times \text{quality factor} = \text{grays} \times \text{quality factor}$$

$$\text{rem} = \text{absorbed dose in conventional units} \times \text{quality factor} = \text{rads} \times \text{quality factor}$$

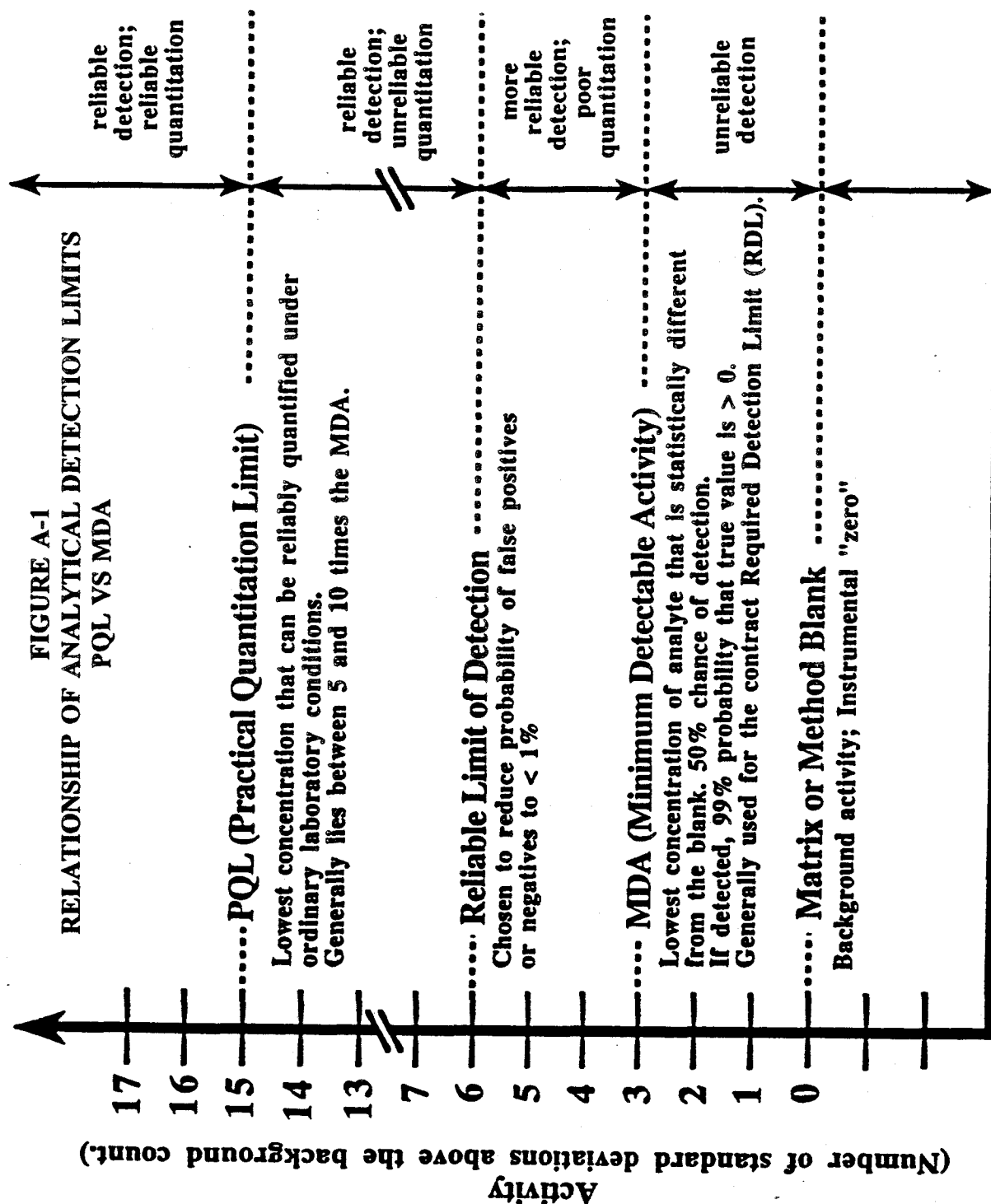
The quality factors are based on whole body exposure. Sometimes additional weighting factors are used when organs of high sensitivity receive concentrated doses.

The quality factors in Table 5 show that neutrons cause more biological damage per gray or rad than gamma-particles, for example. Sieverts and rems are the product of two quantities: the first is the energy absorbed, as given by grays or rads; the second is the quality factor, which depends on the type of radiation. The quality factor is an empirical quantity that relates a tissue dosage unit (sievert or rem) to an energy absorption unit (gray or rad) by:

$$\text{number of sieverts or rems} = \text{number of grays or rads} \times \text{quality factor}$$

Note again that there is no time factor and that sieverts and rems, like grays and rads, are dose units and not rate units. Rems per hour would indicate a dose rate.

FIGURE A-1
RELATIONSHIP OF ANALYTICAL DETECTION LIMITS
PQL VS MDA



APPENDIX B

**SELECTED COSTS AND
VENDOR INFORMATION**

TABLE B-1
CONCEPTUAL FULL SCALE
TREATMENT SYSTEM COSTS

Unit Process	Flow Rate (gpm)	Capital Cost (\$)	Operating Cost (\$/Kgal)
System including prechlorination, multi-media greensand filtration, declorination, microfiltration, pH adjustment, and Reverse osmosis. ¹	100	\$125,000	Unavailable
	250	\$275,000	Unavailable
	500	\$450,000	Unavailable
	1000	\$875,000	Unavailable
Coagulation/clarification systems which include chemical feed system, flocculator, tube settler, and clarifier. ²	100	\$56,000	Unavailable
	250	\$115,000	Unavailable
	500	\$160,600	Unavailable
	1000	\$220,000	Unavailable

¹Facsimile Communication, Michael McDonald, Osmonics, Inc.

²Personal Communication, Jack Sampson, Goble-Sampson, Inc.

TABLE B-2
CONCEPTUAL FILTRATION AND
REVERSE OSMOSIS COSTS

Unit Process	Flow Rate (gpm)	Capital Cost (\$)	Operating Cost (\$/Kgal)
Sand or Multimedia Filter	50-100	8,000	.50
	250	15,000	.35
	1,000	25,000	.20
Microfilter Unit	50	5,000	1.10
Ultrafilter Unit	50	8,000	.80
Reverse Osmosis Unit	50	110,000	1.80
Ultrafilter/Reverse Osmosis System ¹	50	200,000	3
Microfilter/Ion Exchange System ²	10	11,700	Unavailable

¹Personal Communciation, Les Bell, Polymetrics, Inc.

²1987 Jefferson County School District actual costs escalated at 4%/yr to 1994 dollars.

TABLE B-3 **EPA ESTIMATED TREATMENT COSTS**

**TABLE 7.—TOTAL PRODUCTION COST OF CONTAMINANT REMOVAL BY BAT ¹ NOT INCLUDING WASTE BY-PRODUCT DISPOSAL COST
(DOLLARS/1,000 GALLONS, LATE 1986 DOLLARS)**

	Population served					
	25-100	100-500	500-1,000	1,000-3,300	3,300-10,000	> 1,000,000
Radium (50% removal):						
Ion exchange	2.60	1.50	0.90	0.58	0.33	0.17
Lime softening, new	6.40	3.00	1.30	0.87	0.54	0.16
Lime softening, modified	2.50	1.70	0.78	0.39	0.11	0.01
Reverse osmosis	5.10	4.00	2.70	2.30	1.30	0.72
Radon (80% removal):						
Packed tower aeration	0.94	0.50	0.26	0.15	0.07	0.05
Uranium (60% removal):						
Coagulation/filtration, modified	4.40	2.10	0.83	0.38	0.10	0.02
Ion exchange	4.10	2.70	2.00	1.70	1.10	1.00
Lime softening, modified	4.30	2.10	0.83	0.47	0.20	0.03
Reverse osmosis	6.20	4.70	3.50	2.70	1.50	0.86

Notes:
¹ Technologies and cost documents, and cost supplements for radium, radon, and uranium (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988e), form the basis for costs. Costs were revised in May, 1990 to account for new system level treatment design flows adopted by EPA (EPA, 1990d).

TABLE 8.—CAPITAL COST OF CONTAMINANT REMOVAL BY BAT ¹

(\$100 Dollars, Late 1986 Dollars)

	Population served					> 1,000,000
	25-100	100-500	500-1,000	1,000-3,300	3,300-10,000	
Radium (50% removal):						
Ion exchange	36	91	180	280	350	31,000
Lime softening, new	79	130	180	240	540	55,000
Lime softening, modified	33	74	140	200	150	400
Reverse osmosis	51	160	340	620	1,000	177,000
Radon (80% removal):						
Packed tower aeration	15	33	58	78	100	13,000
Uranium (60% removal):						
Coagulation/filtration, modified	27	55	96	130	100	480
Ion exchange	41	100	200	310	330	31,000
Lime softening, modified	43	91	160	220	300	480
Reverse osmosis	64	200	500	960	1,400	249,000

Notes:
¹ Technologies and cost documents, and cost supplements for radium, radon, and uranium (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988e), form the basis for costs. Costs were revised in May, 1990 to account for new system level treatment design flows adopted by EPA (EPA, 1990d).

TABLE 9.—OPERATION AND MAINTENANCE COST OF CONTAMINANT REMOVAL BY BAT (K\$/YEAR, LATE 1986 DOLLARS)

	Population served					
	25-100	100-500	500-1,000	1,000-3,300	3,300-10,000	> 1,000,000
Radium (50% removal):						
Ion exchange	1.1	2.8	7.5	17	43	13,000
Lime softening, new	3.8	11	20	28	73	9,700
Lime softening, modified	3.2	6.4	8.2	9.5	9.1	1,100
Reverse osmosis	4.5	16	45	100	200	50,000
Radon (80% removal):						
Packed tower aeration	0.2	0.6	1.4	3.1	7.6	3,400
Uranium (60% removal):						
Coagulation/filtration, modified	5.7	12	15	16	14	1,400
Ion exchange	3.4	12	39	110	250	95,000
Lime softening, modified	3.5	7.4	10	13	16	3,200
Reverse osmosis	5.1	18	52	120	230	59,000

Notes:
¹ Technologies and cost documents, and cost supplements for radium, radon, and uranium (EPA, 1984b; 1985b; 1986b; 1986c; 1987b; 1987c; 1987d; 1988e), form the basis for costs. Costs were revised in May, 1990 to account for new system level treatment design flows adopted by EPA (EPA, 1990d).

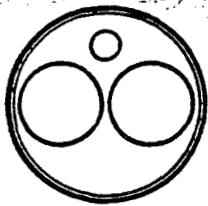
Source of table: National Primary Drinking Water Regulations; Radionuclides; Proposed Rule (56 FR 33050).

TABLE B-4
WASTE MANAGEMENT COSTS FOR POTASSIUM FERRATE TREATMENT
 (6.2x10⁶ gal/yr wastewater treated)

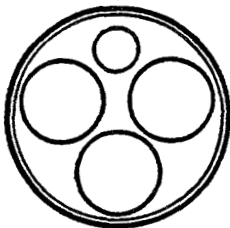
Factor	Annual Cost	Unit Cost
Chemicals:		
Potassium ferrate	\$217,000	\$35/lb
Sodium hydroxide	\$8,010	
Drums of sludge produced	\$349	
Monitoring	\$1,745	\$5/drum
Rotary kiln operating	\$17,450	\$50/drum
Drums of dry sludge	\$244	
Disposal (low-level)	\$258,270	\$1,060/drum (\$5,120/m ³ ; \$145/ft ³)
Total waste management	\$502,475	\$0.08/gal (\$0.02/L)

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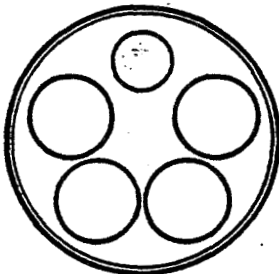
MODEL 16
2 Baskets



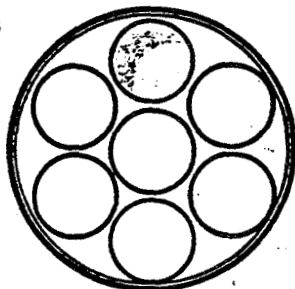
MODEL 18
3 Baskets



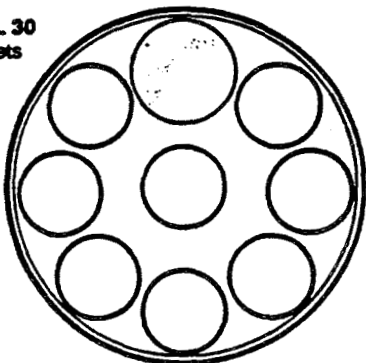
MODEL 22
4 Baskets



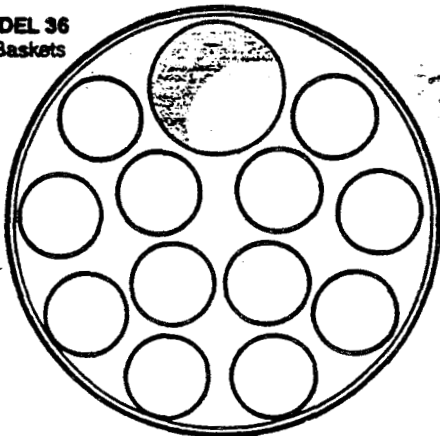
MODEL 24
6 Baskets



MODEL 30
8 Baskets



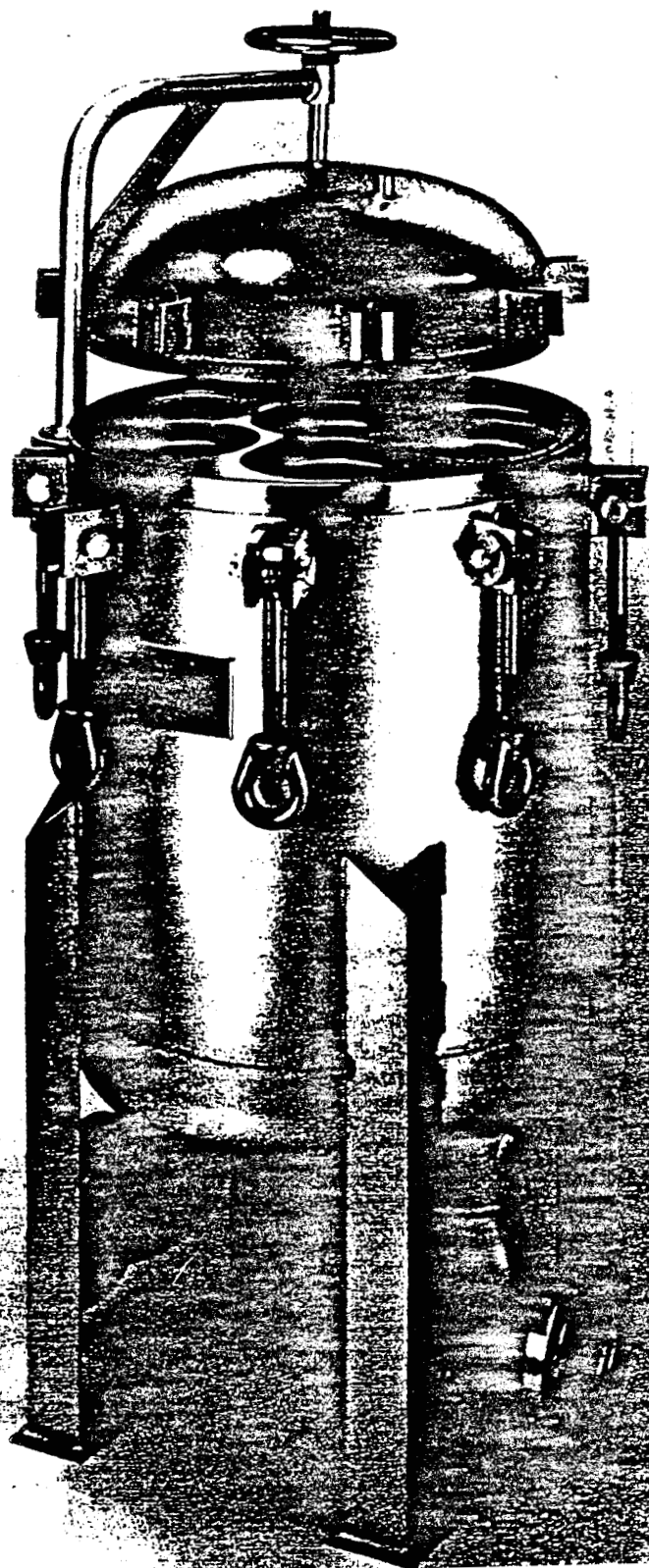
MODEL 36
12 Baskets



Rosedale

Extra-High Capacity

MULTI-BASKET STRAINERS AND MULTI-BAG FILTERS





ROSEDALE HIGH-CAPACITY

Whatever the volume of fluid, type of fluid, or degree of fluid cleanliness required, chances are there's a Rosedale unit that will fit the application perfectly! There are many sizes available, and any one of them can serve as a strainer (for retaining particles down to 74 micron size) or as a filter (for filtration down to one micron) depending upon the type of element selected.

- Housings: Carbon steel or 304 stainless steel
- Baskets: Carbon steel or 304 stainless steel
- Filter Bags: Polyester, polypropylene or nylon

SINGLE BASKET/BAG DESIGN

Model 8—For flow rates to 220 gpm

- Most versatile of the single basket/bag series
- Inner basket or bag option available
- Pipe sizes 2, 3 or 4-inch, NPT or flanged
- Two basket depths—15 or 30 inches (nominal)
- Two pressure ratings—75 psi (with clamp cover) or 150 psi (with eye-bolt cover)
- Side or bottom outlet
- ASME code stamp available

See catalog M8

Model 6—For flow rates to 100 gpm

- Delivers full two square feet of basket or bag surface area without need for ASME code construction
- Pipe sizes 1, 1-1/4, 1-1/2, 2 or 3-inch, NPT or flanged
- Two basket depths—12 or 18 inches
- Two pressure ratings—100 psi (with clamp cover) or 150 psi (with eye-bolt cover)
- Side or bottom outlet

See catalog M6

Model 4—For flow rates to 50 gpm

- Pipe sizes 3/4, 1, 1-1/4, 1-1/2 or 2-inch, NPT
- Two basket depths—6 or 12 inches
- Two pressure ratings—200 psi (with clamp cover) or 300 psi (with eye-bolt cover)
- Side or bottom outlet

See catalog M4

MULTIBASKET/MULTIBAG DESIGN

- Inner basket or bag option available
- ASME code stamp available
- In-line connections

Model 16

Holds 2 baskets/bags. Flows to 400 gpm.
Pipe sizes 2, 3, 4-in., flanged.

Model 18

Holds 3 baskets/bags. Flows to 600 gpm.
Pipe sizes 2, 3, 4-in., flanged.

Model 22

Holds 4 baskets/bags. Flows to 800 gpm.
Pipe size 3, 4, 6-in., flanged.

Model 24

Holds 6 baskets/bags. Flows to 1200 gpm.
Pipe sizes 3, 4, 6-in., flanged.

Model 30

Holds 8 baskets/bags. Flows to 1600 gpm.
Pipe sizes 4, 6, 8-in., flanged.

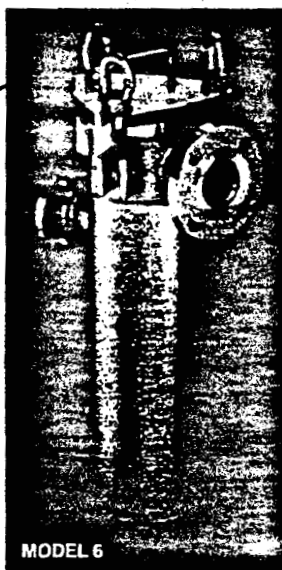
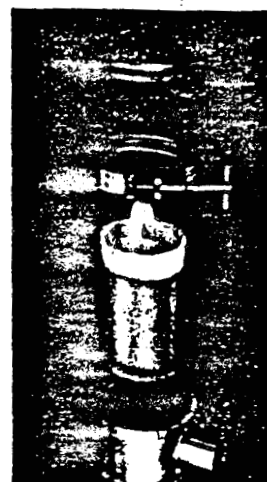
Model 36

Holds 12 baskets/bags. Flows to 2000 gpm.
Pipe sizes 6, 8, 10-in., flanged.

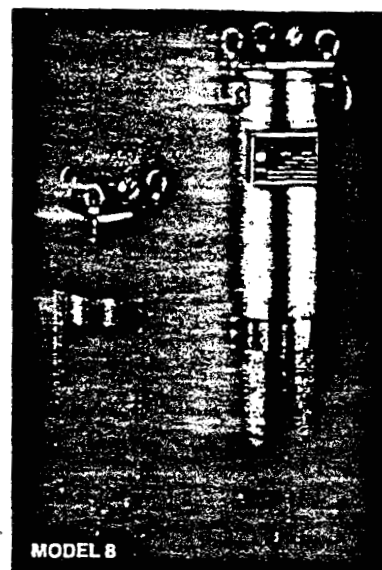
See catalog MB



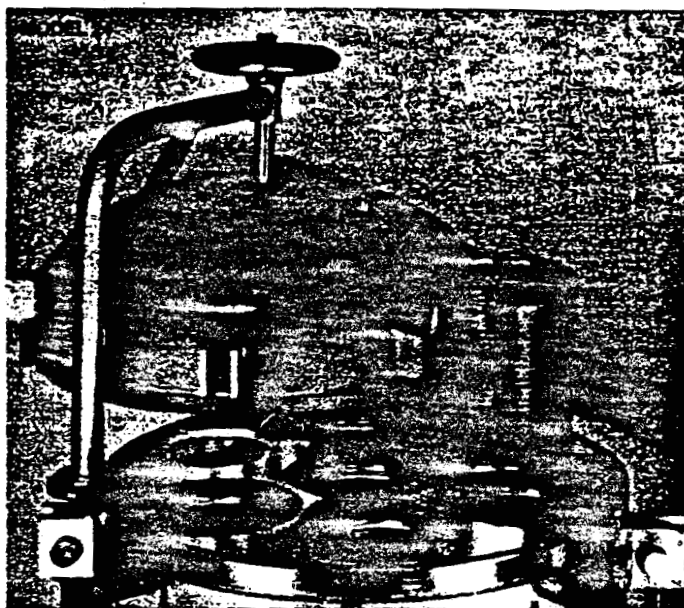
MODEL 4



MODEL 6

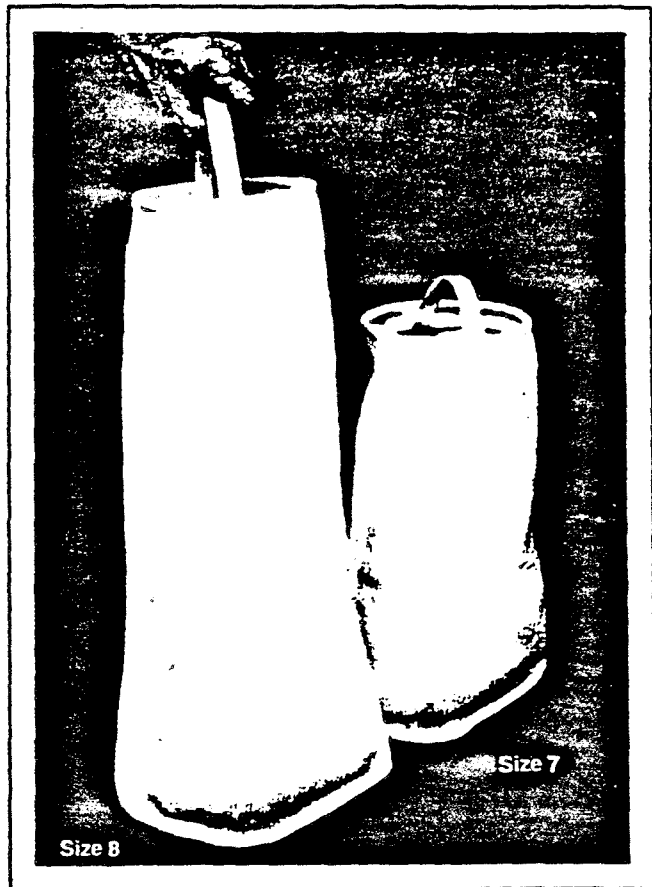


MODEL 8



COMPARATIVE PARTICLE SIZE

U.S. MESH	INCHES	MICRONS
3	.265	6730
3½	.223	5660
4	.187	4760
5	.157	4000
6	.132	3360
7	.111	2830
8	.0937	2380
10	.0787	2000
12	.0661	1680
14	.0555	1410
16	.0469	1190
18	.0394	1000
20	.0331	841
25	.0280	707
30	.0232	595
35	.0197	500
40	.0165	420
45	.0138	354
50	.0117	297
60	.0098	250
70	.0083	210
80	.0070	177
100	.0059	149
120	.0049	125
140	.0041	105
170	.0035	88
200	.0029	74
230	.0024	63
270	.0021	53
325	.0017	44
400	.0015	37



STANDARD FIBERS AND MICRON RATINGS

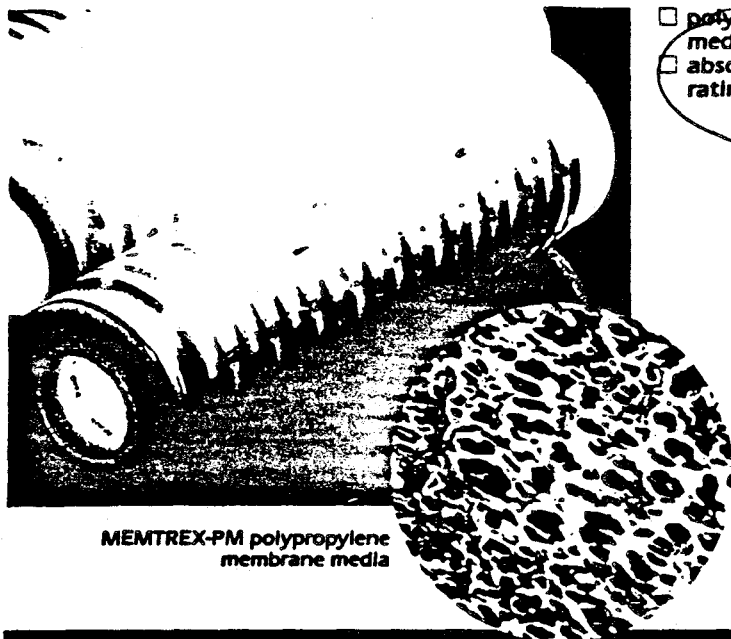
CONSTRUCTION	FIBER	AVAILABLE MICRON RATINGS																	
		1	3	5	10	15	25	50	75	100	125	150	175	200	250	300	400	600	800
Felts	Polyester	•	•	•	•	•	•	•	•	•				•					
	Polypropylene	•	•	•	•		•	•		•									
Multifilament meshes	Polyester								•	•	•	•		•	•	•	•		•
	Nylon									•		•							•
Monofilament meshes	Nylon							•	•	•	•	•	•	•	•	•	•	•	•
	Polypropylene															•		•	

COMPATIBILITY AND TEMPERATURE LIMITS FOR STANDARD BAG MATERIALS

FIBER	COMPATIBILITY WITH							TEMPERATURE LIMITATIONS (max. deg F)
	ORGANIC SOLVENTS	ANIMAL VEGETABLE & PETRO OILS	MICRO-ORGANISMS	ALKALIES	ORGANIC ACIDS	OXIDIZING AGENTS	MINERAL ACIDS	
Polyester	Excellent	Excellent	Excellent	Good	Good	Good	Good	300
Polypropylene	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Good	225
Nylon	Excellent	Excellent	Excellent	Good	Fair	Poor	Poor	325

FILTER BAG SIZES

USED ON ROSEDALE MODEL NO.	BAG SIZE	LENGTH (inches)	DIAMETER (inches)	SURFACE AREA (sq. ft.)	BAG VOLUME (gallons)
4-6	3	8	4.12	0.5	0.5
4-12	4	14	4.12	1.0	1.0
6-12	7	15	5.10	1.3	1.3
6-18	8	21	5.10	2.0	1.5
8-15	1	16.5	7.06	2.0	2.1
8-15	1 (inner)	14.5	5.75	1.6	1.7
8-30, 16, 18, 22, 24	2	32	7.06	4.4	4.6
8-30, 16, 18, 22, 24	2 (inner)	30	5.75	3.6	3.8



MENTREX-PM polypropylene
membrane media

- ☐ polypropylene-membrane media
- ☐ absolute micron retention ratings: 0.1 and 0.2 μm

Features and Benefits

- ☐ true membrane filter
- ☐ hydrophobic media
- ☐ broad chemical compatibility at less cost than fluoropolymers
- ☐ high flow rates
- ☐ all polypropylene components
- ☐ low extractables
- ☐ no adhesives
- ☐ integrity tested during manufacture
- ☐ traceable—all cartridges stamped with identification and lot number
- ☐ all filter materials are listed by the FDA for food and beverage contact

NOTE: In aqueous liquid microfiltration applications, MENTREX-PM must first be wet with a non-aqueous water miscible fluid such as isopropyl alcohol (IPA) to initiate aqueous fluid flow.

Typical Liquid Filtration Applications

- ☐ final filtration of solvents, acids, bases
- ☐ filtration at etch benches
- ☐ chemical final filtration
- ☐ photoresist final filtration
- ☐ reagent and electronic grade chemicals
- ☐ magnetic media chemicals
- ☐ cosmetics

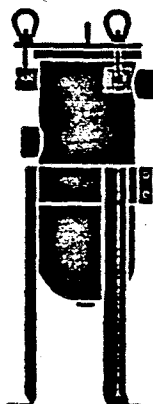
ROSEDALE STRAINERS & BAG FILTERS



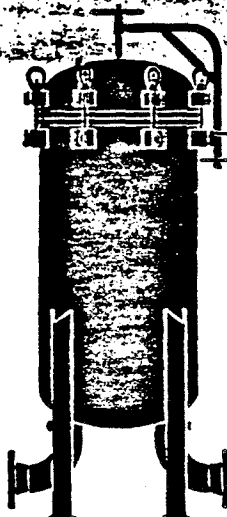
Model 4



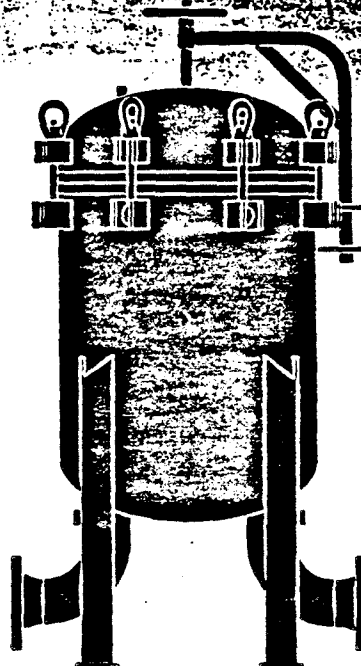
Model 6



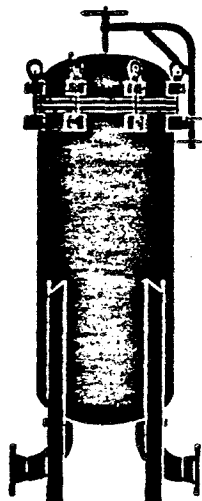
Model 8



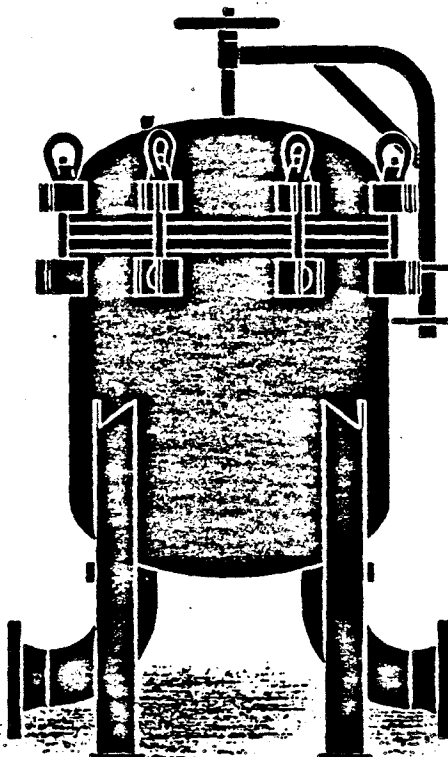
Model 18



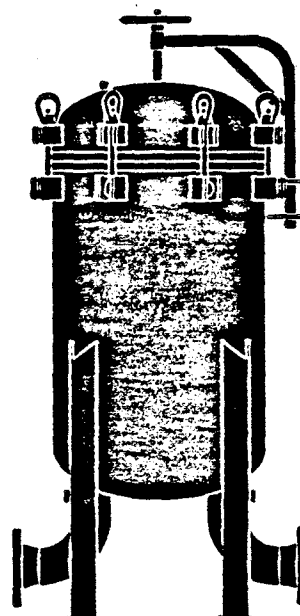
Model 30



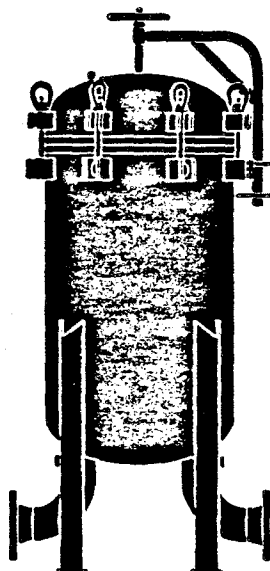
Model 16



Model 36



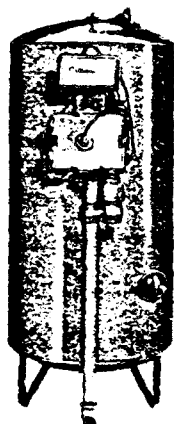
Model 24



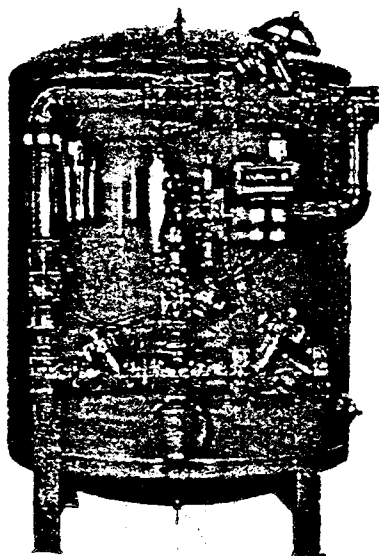
Model 22



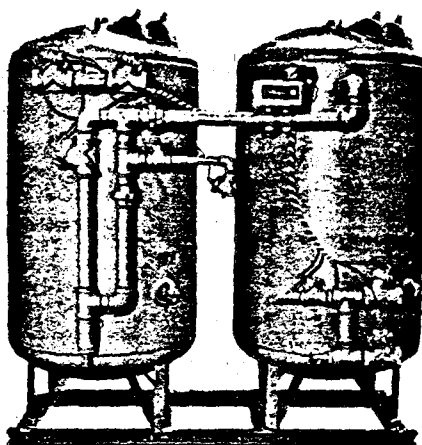
FILTRATION



HD AND HR MODEL
FILTERS THROUGH 20-36" DIAMETER



HD AND HR MODEL
FILTERS 42" DIAMETER AND LARGER



MULTI-TECH FILTER SYSTEM

PRODUCT FEATURES

PROCESS — The Culligan Depth Filter uses a multi-filtration process. Large particulate matter is captured by coarser, lighter media near the top of the filter bed. Particles continue down to the successive lower media levels, where particles as small as 10 microns are captured by finer, heavier media. The density differences between media allows for layer separation after backwashing. The Culligan filter utilizes activated carbon supported gravel underbed for dechlorination, plus the removal of taste, odors and organic material.

RUGGED TANKS — Designed for 100 psi working pressure, hydrostatically tested to 150 psi. 12-inch and 16-inch tanks are made of rugged steel with a corrosion proof vinyl bag liner, high gloss epoxy exterior finish carry a 12-year limited warranty. 20-inch and larger feature heavy gauge steel construction, coated inside with baked-on phenolic epoxy, and outside with a rust primer, covered by a 5-year limited warranty. ASME construction available.

FILTER MEDIA — the multi-media sand and gravel in the Depth Filters and the carbon used in the Culligan are specially selected and packaged separately for installation. Detailed instructions are provided. Supervision by the local Culligan service representative for proper loading of the media and initial start-up are available.

CULLIGAN VALVES are hydraulically activated timer/controller which automatically causes backwash/rinse of the filter bed on an adjustable, pre-set schedule depending upon the turbidity of the water supply.

FLOW CONTROLS are self-adjusting to regulate service and backwash rates regardless of fluctuating water pressure, thus helping to prevent any loss of media from the tank.

OPTIONAL FEATURES — ASME code tank construction is available for all filters except 12 and 16-inch.

PRESSURE DIFFERENTIAL control systems for backwash cycles when pressure drop across the filter increases to maximum level are available as an option for single and duplex installations.

ALTERNATORS for duplex installation are available as an option to cycle two units so that one unit is always in "line" while the other is backwashing or on standby.

MULTI-TECH™ FILTRATION is a three-step process: chemical feed, contact flocculation and multi-media filtration. Turbidity and organic matter are removed from drinking water for small communities, and high quality water for industrial processes.

QUADRA-KLEEN™ Backwash Systems are available for Depth Filters. This unique control features three backwash plus rinse to thoroughly clean the filter bed. Recommended when water is very high in iron or slime.

Design Data

CULLAR. FILTERS

DEL.	FLOW RATES					TANK ⁽²⁾ SIZE (IN)	PIPE SIZE		MEDIA VOL. STD. FT ³	DIMENSIONS ⁽¹⁾			WEIGHT		MODEL
	TASTE, ODOR, & ⁽¹⁾ ORGANIC REMOVAL		DECHLORINATION ⁽²⁾		BACK WASH GPM		SERVICE (IN)	DRAIN (IN)		WIDTH IN.	DEPTH IN.	HEIGHT IN.	SHIP LB.	OPERAT. LB.	
	FLOW GPM	DROP PSI	FLOW GPM	DROP PSI											
-12R	5	1.0	8	7	8	12x37	1½	¾	1.4	14	12	53	141	285	PV-12R
-16R	7	1.0	14	4	15	16x48	1½	1	2.8	17	20	65	305	520	PV-16R
-20	12	2.0	22	5	20	20x54	1½	1	6.0	21	36	69	670	1,275	HR-20
-24	15	2.0	31	8	30	24x54	1½	1	8.0	25	40	69	835	1,625	HR-24
-30	25	3.0	49	10	50	30x60	2	2½	14.0	31	46	77	1,330	2,525	HR-30
-36	35	4.0	71	10	70	36x60	2	2½	20.0	37	54	84	1,810	3,575	HR-36
-42	50	4.0	100	14	90	42x60	2½	2½	24.0	43	51	86	3,200	5,120	HR-42
-48	65	4.0	125	16	130	48x60	2½	3	30.0	49	60	92	4,520	7,120	HR-48
-54	80	6.0	150	18	160	54x60	2½	3	40.0	55	71	94	5,640	9,025	HR-54
-60	100	4.0	200	13	210	60x60	3	3	48.0	61	98	98	6,900	11,160	HR-60

DEPTH FILTERS

DEL	FLOW RATES						TANK ⁽²⁾ SIZE (IN)	PIPE SIZE (IN)		MEDIA VOL. STD. FT ³	DIMENSIONS			WEIGHT		MODEL
	CONTINUOUS ⁽⁴⁾		PEAK ⁽⁵⁾		BACKWASH			INLET & OUTLET	DRAIN		WIDTH IN.	DEPTH IN.	HEIGHT IN.	SHIP LB.	OPERAT. LB.	
	FLOW GPM	DROP PSI	FLOW GPM	DROP PSI	STD. GPM	QUAD. GPM										
-12D	8	2	12	4	10	—	12x37	1½	¾	1.5	14	18	53	222	365	PV-12D
-16D	14	3	21	7	20	—	16x37	1½	1	2.8	17	20	53	410	615	PV-16D
-20	22	7	45	10	30	50	20x54	1½	1	6.0	21	36	69	975	1,600	HD-20
-24	31	10	65	16	50	80	24x54	1½	2½	8.0	25	40	69	1,315	2,150	HD-24
-30	49	10	100	16	70	120	30x60	2	2½	13.0	31	46	77	2,015	3,275	HD-30
-36	71	10	140	16	90	160	36x60	2½	2½	19.0	37	54	84	2,970	4,750	HD-36
-42	95-142	5-10	190	17	136	226	42x60	3	3	25.0	43	51	86	4,980	6,850	HD-42
-48	125-187	6-10	250	16	188	324	48x60	3	3	34.0	49	62	92	6,300	8,850	HD-48
-54	160-240	5-8	320	13	210	398	54x60	4	3	42.0	55	72	94	8,000	11,290	HD-54
-60	200-300	4-9	400	14	270	430	60x60	4	3	52.0	61	77	98	9,770	13,990	HD-60
-72	290-425	4-9	560	14	400	—	72x60	6	4	75.0	73	88	94	14,150	20,100	HD-72
-84	390-575	4-9	770	14	540	—	84x60	6	4	106.0	85	94	97	19,240	27,300	

(1) Taste, odor, and organic removal based on 5 gpm per square foot of filter area.
 Chlorination flow rate can be set up to 10 gpm per square foot of filter area.
 Dimensions are diameter by straight side sheet.

(2) Normal Service Range based on 10 gpm per square foot of filter bed area.
 (3) Peak Flow based on 20 gpm per square foot of filter bed area, not recommended for extended periods of time.
 (4) Does not include operating and maintenance spaces, ASME code tanks are slightly taller.

NOTE: CONSULT FACTORY FOR WATER RECLAMATION APPLICATIONS.

Multi-Tech Systems

Design Data

MODEL	DAILY CAPACITY ⁽¹⁾	SERVICE FLOW RATE PER TANK ⁽²⁾		BACKWASH FLOW RATE ⁽³⁾	TANK DIAMETER	PIPE SIZE ⁽⁴⁾	MODEL
		NORMAL	MAXIMUM				
MT-20	0.065 MGD	15 gpm	22 gpm	30 gpm	20 in.	1½ in.	MT-20
MT-24	0.095 MGD	22 gpm	30 gpm	50 gpm	24 in.	1½ in.	MT-24
MT-30	0.150 MGD	35 gpm	50 gpm	70 gpm	30 in.	2 in.	MT-30
MT-36	0.215 MGD	50 gpm	70 gpm	100 gpm	36 in.	2 in.	MT-36
MT-42	0.280 MGD	65 gpm	95 gpm	130 gpm	42 in.	2½ in.	MT-42
MT-48	0.367 MGD	85 gpm	125 gpm	170 gpm	48 in.	3 in.	MT-48
MT-54	0.475 MGD	110 gpm	160 gpm	220 gpm	54 in.	3 in.	MT-54
MT-60	0.580 MGD	135 gpm	190 gpm	270 gpm	60 in.	4 in.	MT-60
MT-72	0.842 MGD	195 gpm	280 gpm	400 gpm	72 in.	4 in.	MT-72
MT-84	1.15 MGD	265 gpm	380 gpm	530 gpm	84 in.	6 in.	MT-84
MT-96	1.52 MGD	350 gpm	500 gpm	700 gpm	96 in.	6 in.	MT-96
MT-120	2.37 MGD	550 gpm	780 gpm	1100 gpm	120 in.	6 in. (8 in.)	MT-120

- (1) Daily Capacity based on 24 hour operation of 3 train system operating at normal service flow rate of 7 gpm/ft² per train.
 (2) Service flow rates based on 7 gpm/ft² per train. When one train of the 3 train system is in backwash, the remaining 2 trains will operate at 10.5 gpm/ft².
 (3) The backwash flow rate of both the clarifier and filter are approximately 14 gpm/ft². The clarifier eductor draws 2-3 cfm/ft² air during the scour cycle for additional mineral bed expansion.
 (4) Pipe size selection is based on a maximum velocity of 5 fps at the Normal Service flow rate.
 (5) Total water usage per train is 225 gallons per sq ft of filter tank area. This includes 140 gallons of influent water for clarifier backwash and system rinse plus 85 gallons of filtered water for depth filter backwash.



HI-FLO™

DEPTH FILTERS FOR SEDIMENT REMOVAL

SPECIFICATIONS AND OPERATING DATA

HI-FLO MULTI-MEDIA™ DEPTH FILTERS

Model Number	Service Flow Rate @ Pressure Drop				Back- wash Rate gpm*	Tank Size Inches	Inlet/ Outlet Pipe Size In.	Media Volume Std. Cu. Ft.	Approx. Ship Weight lbs.
	Peak		Normal						
	Flow gpm	Drop psi	Flow gpm	Drop psi					
HD-20	45	10	22	7	30	20 x 54	1½	5.8	975
HD-24	65	16	31	10	50	24 x 54	1½	8.4	1315
HD-30	100	16	49	10	70	30 x 60	2	13	2015
HD-36	140	16	71	10	90	36 x 60	2½	19	2970
HD-42	190	17	95	5	135	42 x 60	3	25	4980
HD-48	250	16	125	6	175	48 x 60	3	33	6300
HD-54	320	13	160	5	220	54 x 60	4	42	8000
HD-60	400	14	200	4	270	60 x 60	4	52	9800
HD-72	560	14	290	4	400	72 x 60	6	75	17000
HD-84	770	14	390	4	540	84 x 60	6	103	23000

*With Quadra Kleen™ option, backwash flow rate is increased by 70%

Note: Operational, maintenance and replacement requirements are essential for this product to perform as advertised.



Commercial/Industrial Systems
One Culligan Parkway, Northbrook, IL 60062 (312-498-2000)

QUALITY WATER AT WORK
T.M.

EXCELLENCE

in Design and Construction

EXCLUSIVE WARECO™ PRESSURE VESSELS

All EcoWater Industrial System filters are superior in design and construction because they use the patented Wareco™ Polybond™ pressure vessel, available only from EcoWater Industrial Systems.

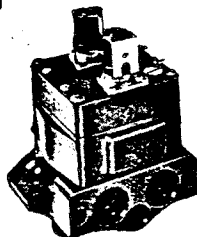


A thick virgin polyethylene liner is permanently bonded to the tank interior under a high heat fusion process to form a tank within a tank. Tanks are made of industrial quality steel, and are a smooth 7 mil application of Epoxy Mastic Enamel dries to a durable 6 mil coat of rust and corrosion protection. A quality finish for a quality tank.

Tank closures are protected by the bonded lining and are fitted with O-ring seals so that water never touches metal. After construction, Wareco tanks are 100% spark tested for lining integrity to detect even the most minute hole, then 100% pressure tested.

MULTI-FUNCTION VALVE

All filters use the EcoWater Industrial Systems 5-cycle, non-corrosive phenolic central control valve for positive control of all service, backwash and rinse cycles. The valve is top mounted for easy connection to overhead piping, and may be removed for service without disturbing existing plumbing.



EFFICIENT BACKWASHING

Filters backwash automatically, initiated by time clock, pressure drop, or volume of water used. Backwash can also be manually initiated by pushbutton.

Backwash includes an upflow wash to loosen and fluff the media for thorough contact of water with trapped particles for more effective cleaning. Backwash rates are pre-set to maximize bed expansion without media loss.

After backwash, a downflow rinse is done at full service flow rate to purge the bottom of the bed of particulate matter, and to pack the bed for more efficient filtering. In multiple units, filters in service provide water for backwashing, so that turbidity does not accumulate in the bottom of the bed.

CHOICE OF CONTROLS

Any EcoWater Industrial Systems control – time clock Electro-Selector, duplex alternator, or Continuous Sequence – may be used with any filter. Selection is based on the kind of performance desired, conditions of use, and whether more than one tank is used. In Continuous Sequence multiple tank systems, filters are backwashed in sequence and immediately returned to service to increase system filtering capacity and to assure a constant supply of filtered water. Continuous Sequence can also hold tanks on stand-by for later return to service, thus functioning as a multi-tank alternator.

TURBIDITY REMOVAL

Multi-Clean™

MULTI-MEDIA DEPTH FILTERS

for high efficiency removal of particulate matter

EcoWater Industrial Systems Multi-Clean™ multiple media turbidity filters offer users a highly efficient means of removing suspended particulate matter from water.

The three layers of media in Multi-Clean filters are specially selected for their particle size, specific gravity, and proven ability to trap particles of specific size ranges. As water flows downward through the bed, it encounters layers of media with decreasing porosity, so that successively smaller particles are trapped in each layer, providing true depth filtration. The top layer traps larger particles and debris, the middle layer traps coarse and intermediate size particles, and the bottom layer traps particles as small as 10 microns. More importantly, each layer prevents the larger particles from contacting the finer media so that they can function effectively in trapping particle sizes for which they are designed.

EcoWater Industrial Systems Filters are specially designed to eliminate the problems of media washout and intermixing for best long term performance. EcoWater Industrial Systems has determined that three properly selected media offer the optimum combination of filtration efficiency, economy and service reliability.

EcoWater Industrial Systems Multi-Clean depth filters provide removal of particles as small as 10 microns routinely. With chemical filter aids, particles as small as one micron can be removed.

The filters provide an efficient means of providing high clarity water either for direct use or for feeding water to other units in a system such as softeners, deionizers, or reverse osmosis units.

EFFECTIVE RESTRATIFICATION

Restratification of the several media after backwashing is critical to depth filter efficiency. Careful selection of the three media assures positive relayering. This design concept has proven to be highly effective in both prototype and field units in thousands of applications.

CHOICE OF SIZES, CAPACITIES

Standard filters are available in the series M, H, or L design configurations. Tank diameters range from 10 to 48 inches; service flow rates range from 4 to 190 gpm.

CHEMICAL FEEDERS

EcoWater Industrial Systems offers a line of chemical proportioning feeders for feeding coagulants or flocculants to turbidity filters to increase filtering efficiency. Without the addition of a filter aid, turbidity filters routinely remove particles as small as 10 microns; with filter aids particles as small as one micron can be removed.

Several size feeders are offered, so that the feeder matches filter size. All feeders have adjustable rates of feed so that the user can make fine adjustments on the job.

FILTERS



ECO WATI
INDUSTRI
SYSTEM

5-CYCLE MULTI-FUNCTION VALVE

Tough, corrosion-resistant reinforced phenolic. Proven hydraulic operation. Modular design for low-cost maintenance. Top mounted for easy piping connections.

BONDED TANK LINING

Exclusive Wareco™ Polybond™ heat-fused tank lining for maximum corrosion resistance . . . a tank within a tank.

TANK FINISH

All tanks are protected on the outside with an epoxy coating.

CHOICE OF CONTROL

Model ESM for elapsed time and Model DP for pressure differential initiated backwash. Continuous Sequence control for multiple tank systems.

CORROSION-RESISTANT CLOSURES

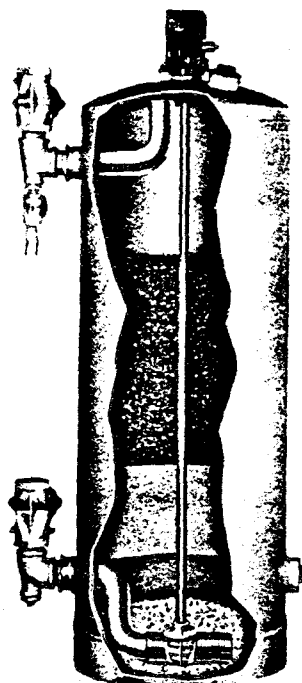
All tank closures seat on O-ring seals resting on plastic inner lining. Water never touches steel.



SERIES M

SELF-CLEANING DISTRIBUTOR

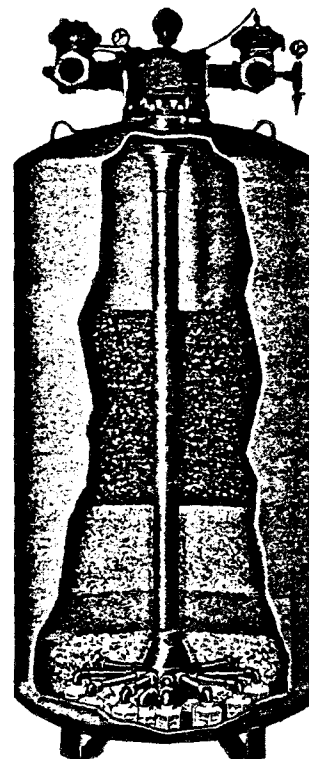
Large collector with quartz underbedding to equalize flow throughout bed; cleans itself during backwash. One-inch openings for high flow, minimum pressure drop in small systems.



SERIES H

HIGH FLOW DISTRIBUTOR SYSTEM

Dual distributors and quartz underbedding equalize flow throughout the filter bed during backwash and provide high service flow with minimum pressure drop.



SERIES L

EFFICIENT HUB RADIAL DISTRIBUTOR

Hub radial construction, quartz underbedding to equalize flow throughout filter bed. Full 3-inch internal plumbing gives high flow, minimum pressure drop.

Specifications

Series	Model	Flow Rate — GPM*		Pipe Size	Tank Size	Floor Space L x D x H	Operating Limits
		Cont.	Peak				
M	MC10	8	11	1"	10" x 52"	10" x 12" x 60"	Pressure: 10" - 30" — 30 p.s.i. - 125 p.s.i. 2 bar - 8.4 bar 36" - 48" — 30 p.s.i. - 100 p.s.i. 2 bar - 6.8 bar Temperature: 35°F - 125°F 1.6°C - 51.6°C Electrical 120V. - 60Hz Requirements: 220V. - 50Hz.
	MC12	12	16	1"	12" x 52"	12" x 19" x 60"	
H	MC14	16	21	1½"	14" x 66"	21" x 16" x 75"	
	MC18	26	35	1½"	18" x 66"	25" x 20" x 75"	
	MC24	50	65	1½"	24" x 66"	32" x 26" x 75"	
	MC30	75	100	2"	30" x 66"	39" x 32" x 75"	
	MC36	105	140	2½"	36" x 70"	48" x 38" x 81"	
L	MC42	145	190	3"	42" x 70"	44" x 44" x 84"	
	MC48	190	250	3"	48" x 70"	50" x 50" x 84"	

*Turbidity 50 NTU or less. Higher turbidity levels can be treated at lower flow rates. Consult factory.

SPECIFICATIONS AND DESIGN DATA

SERIES	MODEL	CONTINUOUS		PEAK		PIPE SIZE IN.	BW RATE GPM	MODEL	CONTINUOUS		PEAK		PIPE SIZE IN.	BW RATE GPM	FAST RINSE GPM	TANK SIZE IN.	MEDIA QTY CU. FT.	SPACE REQUIREMENTS L x D x H-IN.	WEIGHT POUNDS	
		FLOW GPM	DROP PSI	FLOW GPM	DROP PSI				FLOW GPM	DROP PSI	FLOW GPM	DROP PSI							SHIP	OPER

Carbon Filters

FOR CHLORINE, TASTE, ODOR FM-6 ACTIVATED CARBON (1)										FOR ORGANICS REMOVAL FM-44 ACTIVATED CARBON (2)									
M	CC10	6	5	10	12	1"	2.4	CL10	2.5	2		1"	2.4	9	10 x 52	1.25	10 x 12 x 60	135	245
	CC12	10	10	16	18	1"	3.5	CL12	4	2		1"	3.5	9	12 x 52	2	12 x 14 x 60	195	340
	CC14	15	12	24	25	1"	5	CL14	6	2		1"	5	9	14 x 66	3	14 x 16 x 75	350	625
								CL18	10	2		1"	7	9	18 x 66	5	18 x 22 x 75	465	915
H	CC18	25	5	40	10	1½"	7							18	18 x 66	5	25 x 20 x 75	515	965
	CC24	50	10	75	19	1½"	13	CL24	20	3		1½"	13	18	24 x 66	10	32 x 26 x 75	835	1700
	CC30	75	7	120	14	2"	19	CL30	30	3		1½"	19	18	30 x 66	15	39 x 32 x 75	1385	2610
	CC36	100	6	125	8	2"	27	CL36	40	4		1½"	27	18	36 x 70	20	48 x 38 x 81	2170	4046
L	CC42	150	8	180	11	2½"	40	CL42	60	8		1½"	40	60	42 x 70	30	44 x 44 x 84	2810	5460
	CC48	200	11	270	17	3"	50	CL48	80	3		2"	50	60	48 x 70	40	50 x 50 x 84	3600	6890

Depth and Single-Media Turbidity Filters

MULTI-CLEAN MULTI-MEDIA DEPTH FILTER (3)										SINGLE MEDIA FILTER FM-11 FILTER AG (4)										
M	MC10	8	6	11	12	1"	7	TF10	2.5	2	3.5	3	1"	5	9	10 x 52	1.25	10 x 12 x 60	180/135	300/245
	MC12	12	7	16	14	1"	10	TF12	4	2	5.5	3	1"	7	9	12 x 52	2	12 x 14 x 60	285/195	430/340
								TF14	5	2	7	3	1"	10	9	14 x 66	3	14 x 16 x 75	350	625
H	MC14	16	7	21	14	1½"	15								18	14 x 66	3	21 x 16 x 75	430	705
	MC18	26	7	35	14	1½"	25	TF18	9	2	12	3	1½"	17	18	18 x 66	5	25 x 20 x 75	740/515	1180/965
	MC24	50	8	65	15	1½"	47	TF24	16	2	22	3	1½"	27	18	24 x 66	10	32 x 26 x 75	1385/935	2150/1700
	MC30	75	6	100	14	2"	74	TF30	25	2	35	4	1½"	37	18	30 x 66	15	39 x 32 x 75	2060/1385	3285/2610
	MC36	105	6	140	14	2½"	97	TF36	35	3	50	6	1½"	70	18	36 x 70	20	48 x 38 x 81	3070/2170	4946/4046
L	MC42	145	6	190	14	3"	144	TF42	50	3	70	6	2"	100	60	42 x 70	30	44 x 44 x 84	4280/2810	6910/5460
	MC48	190	7	250	15	3"	160	TF48	65	3	90	6	2½"	120	60	48 x 70	40	50 x 50 x 84	5400/3600	8690/6990

Iron and Neutralization Filters

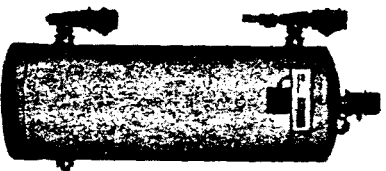
FOR IRON AND HYDROGEN SULFIDE FM-8 GREENSAND (4)								FOR NEUTRALIZATION OF LOW PH FM-2 CALCITE (4)												
M	FG10	2.5	2	3.5	3	1"	5	NT10	2.5	2	3.5	3	1"	5	9	10 x 52	1.25	10 x 12 x 60	210	320
	FG12	4	2	5.5	3	1"	7	NT12	4	2	5.5	3	1"	7	9	12 x 52	2	12 x 14 x 60	315	460
	FG14	5	2	7	3	1"	10	NT14	5	2	7	3	1"	10	9	14 x 66	3	14 x 16 x 75	530	805
	FG18	9	2	12	3	1½"	17	NT18	9	2	12	3	1½"	17	18	18 x 66	5	25 x 20 x 75	815	1265
H	FG24	16	2	22	3	1½"	27	NT24	16	2	22	3	1½"	27	18	24 x 66	10	32 x 26 x 75	1535	2300
	FG30	25	2	35	4	1½"	37	NT30	25	2	35	4	1½"	37	18	30 x 66	15	39 x 32 x 75	2285	3510
	FG36	35	3	50	6	1½"	70	NT36	35	3	50	6	1½"	70	18	36 x 70	20	48 x 38 x 81	3495	5370
L	FG42	50	3	70	6	2"	100	NT42	50	3	70	6	2"	100	60	42 x 70	30	44 x 44 x 84	4710	7260
	FG48	65	3	90	6	2½"	120	NT48	65	3	90	6	2½"	120	60	48 x 70	40	50 x 50 x 84	6000	9290

NOTES: (1) Continuous flow based on 5 GPM per cu. ft. (approx. 15 GPM per sq. ft.)
(2) Continuous flow based on 2 GPM per cu. ft. (approx. 6 GPM per sq. ft.)
(3) Continuous flow based on 15 GPM per sq. ft. of bed area, peak at 20 GPM per sq. ft. for turbidity 50 NTU or less.
(4) Higher NTU can be filtered at lower flow rates. Hours of operation between backwash cycles depend on dirt.

ECO WATER INDUSTRIAL



SERIES H



SERIES M



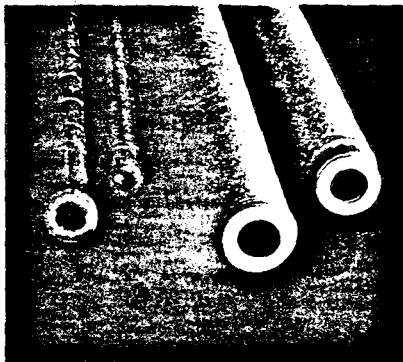
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The PROFILE II filter element's unique continuously graded upstream section is made possible by a proprietary manufacturing method which enables us to change fiber diameter instantaneously and continuously. In the continuously graded section, pore size varies through the range of 40 to 1 to provide multiple levels of effective prefiltration.

The filament diameter of the downstream section of the PROFILE II filter element remains constant, providing constant pore size for reliable, absolute filtration. This is the only absolute-rated depth filter currently available. It is available as fine as 0.5 μ m absolute. We know of no other depth filter available in submicron rated grades.

PROFILE II elements last longer than any competitive depth filter of equal rating because they offer substantially higher void volume. PROFILE II elements can last up to six times as long as conventional depth filters. They are manufactured using 100% polypropylene. They are ideally suited for filtering deionized water supplies, condensate, and as prefilters for reverse osmosis systems.

For more information see Pall Bulletin E1a, PRO 400a, PRE1A and PGG 460.



PROFILE II elements are also available as backwashable septa in standard 1", 1 1/4" and 2" diameter configurations and up to 96" long. For more information contact your local Pall representative.

PROFILE II cartridge grades and their characteristics

Cartridge Grade	Removal Ratings		Clean Pressure Drop	
	Liquid Service Rating in μ m at 99.9%	100%	Liquid Service Aqueous Pressure Drop ⁽¹⁾	Typical Aqueous Flow (gpm/10" Cartridge)
X 005	<0.5	0.5 ⁽²⁾	2.8	1 - 2.5
010	<0.5 ⁽²⁾	1	2.6	1 - 3
020	1.5	2	1.9	1 - 3
030	2.5	3	1.5	2 - 5
X 050	4	5	0.8	3 - 8
070	6	7	0.5	5 - 12
100	9	10	0.3	6 - 15
120	11	12	0.2	6 - 15
150	13	15	0.15	8 - 15
200	18	20	0.10	10 - 15
300	26	30	0.08	10 - 15
400	35	40	0.05	10 - 15
700	70	-	<0.05	10 - 15
900	90	-	<0.05	10 - 15
1200	120	-	<0.05	10 - 15

(1) Pressure drop in PSI per GPM for a single 10" module. For multiple elements, divide by number of modules. For fluids other than water, multiply by viscosity in centipoise.

(2) Extrapolated Values

Sizes and operating characteristics

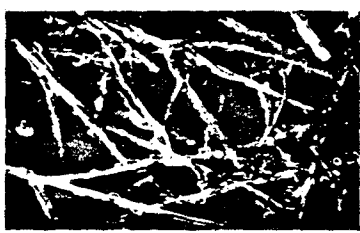
PROFILE II elements are available in 2 1/2" O.D. double open ended and single open ended configurations.

Recommended maximum pressure differential is 60 psi up to 30°C (86°F), 50 psi up to 50°C (122°F), 30 psi up to 70°C (158°F), and 15 psi up to 90°C (194°F).



ULTIPOR GF®/ULTIPOR GF PLUS®

PALL
ULTIPOR GF®
ULTIPOR
GF PLUS®
FILTERS



A rugged, migration-free medium consisting of glass fibers coated with a resin which imparts an enhanced zeta potential and a very strong fiber to fiber bond.



The Ultipor GF and Ultipor GF Plus medium is available with absolute ratings as fine as 0.2 μ m, and is capable of electrostatically stopping particles smaller than 1/3 of the absolute rating.

Ultipor GF/Ultipor GF Plus filters characteristically have triple the dirt capacity of competitive filters, and several grades provide even longer life in systems because they contain prefilter layers.

High void volume (80-85%) provides high flow rates at low initial pressure drop, resulting in longer onstream life and low capital cost (fewer elements per installation).

Sizes and operating characteristics

The nuclear style disposable filters are available in four nominal diameters 2 3/4", 6", 10" and 12". Each is available in lengths up to 40". "Pall-Fit" cartridges, for direct replacement of most existing string-wound cartridges are also available. The recommended maximum pressure differential is 75 PSID up to 120°C (250°F). Filter replacement is recommended at 25 PSID.

For more information see Pall Bulletin PGG 100 or contact your local Pall representative.

Ultipor GF/Ultipor GF Plus cartridge grades and their characteristics

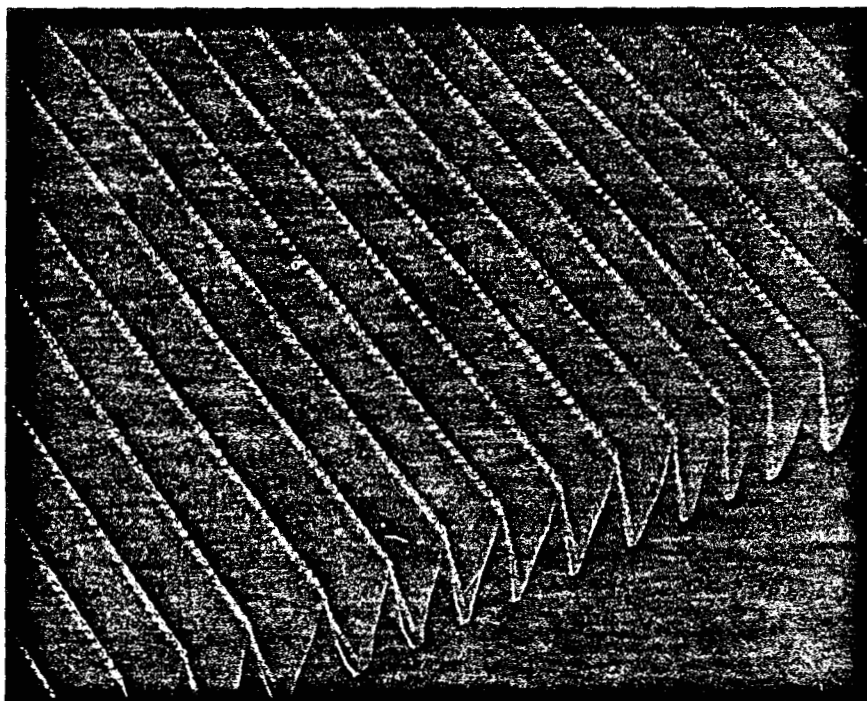
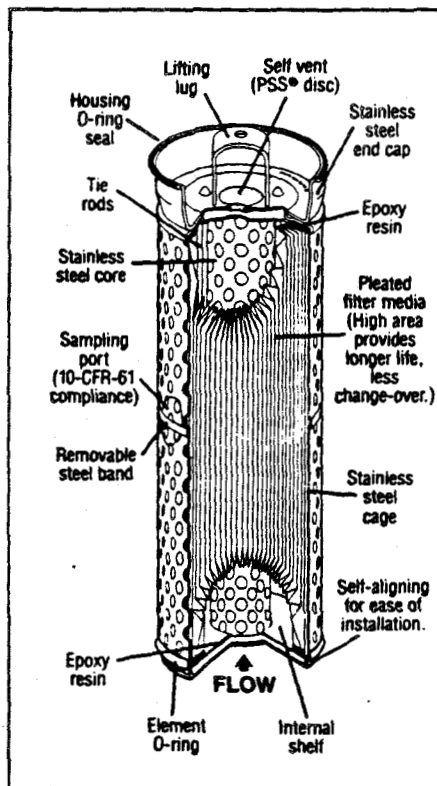
Cartridge Grades	Liquid Service ⁽¹⁾		Gaseous Service (0.3 μ m) DOP Removal %
	Rating in (μ m)	at % Efficiency	
	99%	100%	
X U002	-	0.20	-
U0045	-	0.45	-
U010Z	0.6 ⁽²⁾	1	99.9999
U2-20Z*	0.8 ⁽²⁾	2	99.9998
U030Z	2	3	99.99
U6-40Z*	3.2	6	99.5
U100Z	6	10	98.2
U200Z	17	20	65
U400Z	25	40	60

* These grades are particularly useful as prefilters, in addition to providing absolute removal efficiency.

(1) Liquid service ratings are based on a modified OSU F-2 protocol for recording removal efficiency based on particle counting techniques. For details refer to Bulletin HDC 700a. Submicron grades are rated using standardized bacterial challenges.

(2) Extrapolated Values

Note: Ultipor GF grades provide negative zeta potential. Ultipor GF Plus grades provide positive zeta potential. Z denotes filter grades available as Ultipor GF Plus. Cartridge Grades U002 and U0045 are only available as Ultipor GF.



PALL NUCLEAR STYLE
DISPOSABLE FILTER ELEMENT
FEATURES OF CONSTRUCTION

ULTIPOR GF/ULTIPOR GF PLUS PLEATED MEDIA PACK SECTION

Liquid Recovery

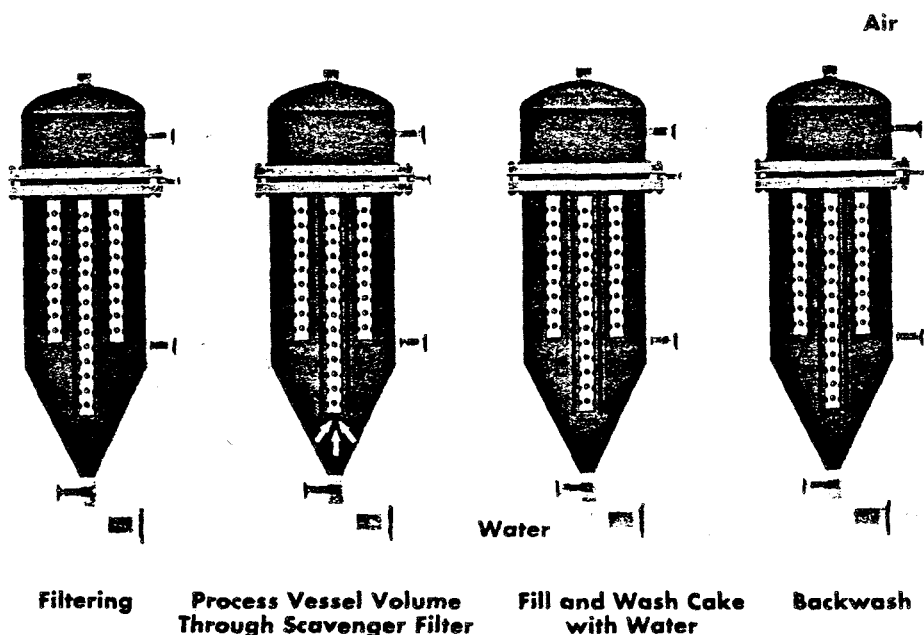


Figure 3. Liquid recovery from backwash fluids.

Generally in a backwash cycle the volume of about one to two filter vessels is disposed of or recycled to somewhere else in the system. In many processes, however, the filtrate is too valuable for even a small quantity to be disposed of. Pall has developed a few simple methods to drain and recover such valuable liquids. One method, for example, is to utilize one or more scavenger filter cartridges near the center of the filter vessel. The scavenger elements help drain the liquid just prior to the backwashing stage. This technique is also useful for minimizing the volume of filtrate that is considered hazardous (see Figure 3).

THE BENEFITS OF PALL BACKWASH FILTRATION SYSTEMS

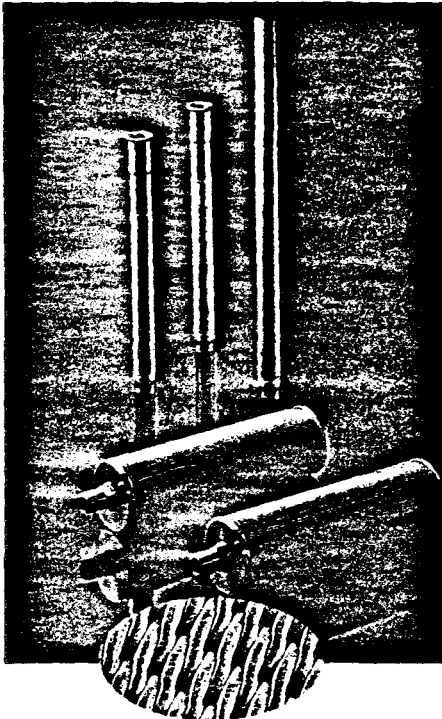
Pall backwash filtration systems are in operation today all over the world, in a wide variety of applications. Among their numerous, proven benefits are the following:

- High-efficiency operation (99.9%) improves product quality, maximizes solids recovery, and helps protect equipment, employees, and the environment.
- The high temperature, pressure, and solids content the systems can handle mean that they can operate in a wide range of applications.
- There are no cloths, bags, or sheets to rupture, which ensures process integrity and minimizes maintenance and replacement costs.
- Every system is fully automated, for reduced labor and consistent performance.
- There are no moving parts, which reduces energy consumption, noise, and maintenance.
- The compact size of even the most complex, high-volume backwash system minimizes product holdup, backwash fluid volume, space requirements, and installation costs.
- Every system, including filter media and assembly material, is designed to meet the requirements of a single specific customer. This degree of customization requires a complete understanding of the entire process, which translates to more efficient operation, less waste, closer conformance to EPA and other governmental agency regulations, and longer filter service life.

PALL FILTERS: THE HEART OF THE BACKWASH SYSTEM

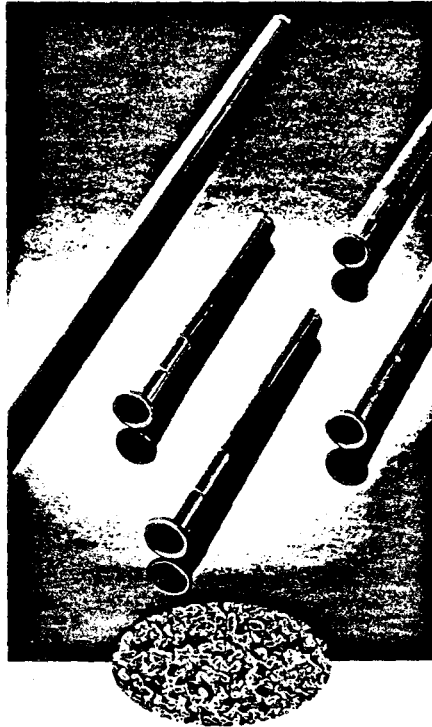
As the actual filtering agent, the Pall filter or septum is the most important component of the backwash system. For backwash applications, Pall offers the broadest array of proprietary metal and synthetic fiber media in the industry. Depending on the particular plant and process, there is a medium that is the right choice for every system. The following Pall products are appropriate for backwash applications (see p.8 for technical data):

PALL RIGIMESH® STAINLESS STEEL WOVEN WIRE MESH FILTERS



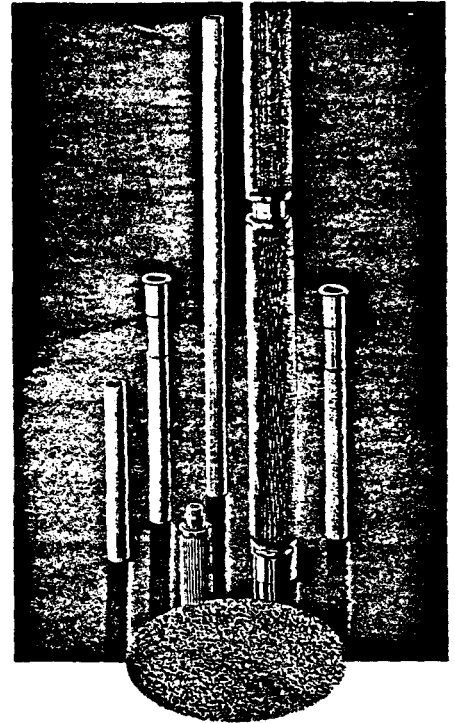
A process pioneered and patented by Pall Corporation permits the use of finer-diameter wires in the manufacture of the Rigimesh stainless steel medium. This results in low pressure drop, more holes per unit area, and better dirt-holding capacity than that of any other woven metal filter. The medium is sintered for superior tensile, yield, shear, and fatigue strength, maintains a uniform pore size, and exhibits no media migration, even under high temperature and pressure. This medium is of particular value for stopping oily waste.

PALL S SERIES POROUS METAL PSS® FILTERS



Manufactured of sintered powder stainless steel, the S Series PSS medium offers exceptionally uniform permeability, with up to 60% of its volume made up of interconnecting voids. It is two to three times more permeable than other filters made from metal powder, thus offering less resistance to flow. Finished elements are free of seams. In addition to the standard PSS sintered stainless (Type 316L), on special order porous metal filters can be furnished in Inconel, nickel, stainless steel Type 300 series, and high nickel molybdenum alloys.

PMM® METAL MEMBRANE FILTERS



Combining the best qualities of Pall's S Series and Rigimesh media, the absolute-rated PMM medium is a thin, sintered matrix of fine stainless steel powder within the porous structure of stainless steel woven wire mesh. The fine powder provides absolute filtration down to 2 microns. The woven wire mesh support structure is exceptionally strong yet thin enough to permit this medium to be pleated into high area filter elements, minimizing resistance to flow. The smooth surface and uniformity of the PMM membrane make it an excellent choice for solids separation in liquid service. It is ideal where precoating is required.

TABLE 1. FILTER ELEMENTS

NOMINAL OUTER DIAMETERS	NOMINAL LENGTHS	MAXIMUM ALLOWABLE DIFFERENTIAL PRESSURE	MAX. ALLOWABLE TEMP.
RIGIMESH FILTERS (NON-PLEATED ELEMENTS)			
1 in. 25mm	23, 46, 69 in. 0.6, 1.2, 1.75m	60 psi forward 4.2 bar	750°F 400°C
2-3/8 in. 60mm	23, 46, 69 in. 0.6, 1.2, 1.75m	50 psi forward 3.5 bar	750°F 400°C
SERIES PSS FILTERS (NON-PLEATED ELEMENTS)			
		GRADE S100	
2-3/8 in. 60mm	20, 40, 60, 80 in. 0.5, 1, 1.5, 2m	12 psi forward 0.8 bar	750°F 400°C
		GRADE S200	
2-3/8 in. 60mm	20, 40, 60, 80 in. 0.5, 1, 1.5, 2m	35 psi forward 2.4 bar	750°F 400°C
PMM FILTERS (NON-PLEATED ELEMENTS)			
1 in. 25mm	23, 46, 69 in. 0.6, 1.2, 1.75m	60 psi forward 4 bar	750°F 400°C
2-3/8 in. 60mm	23, 46, 69 in. 0.6, 1.2, 1.75m	50 psi forward 3.5 bar	750°F 400°C
PMM FILTERS (PLEATED ELEMENTS)			
2-1/2 in. 64mm	16, 32, 48, 64 in. 0.4, 0.8, 1.2, 1.6m	125 psi forward 8.5 bar	750°F 400°C
PMF FILTERS (PLEATED ELEMENTS)			
2-1/2 in. 64mm	16, 32, 48, 64 in. 0.4, 0.8, 1.2, 1.6m	125 psi forward 8.5 bar	600°F 315°C
PROSEP FILTERS (NON-PLEATED ELEMENTS)			
1-1/4 in. 32mm	60 in. 1.5m	100 psid forward 7 bar	120°F 50°C
2 in. 50 mm	40, 60, 80 in. 1, 1.5, 2m	70 psid forward 5 bar	120°F 50°C

TABLE 2. FILTER GRADES AND THEIR CHARACTERISTICS

REMOVAL GRADE	REMOVAL RATING LIQUID SERVICE RATING IN μm	CLEAN PRESSURE DROP LIQUID SERVICE AQUEOUS PRESSURE DROP ⁽²⁾		RECOMMENDED FLOW DENSITY AQUEOUS	
RIGIMESH FILTERS					
R	AT 100% EFFICIENCY ⁽¹⁾ 70	psi/gpm/ft ² 2×10^{-4}	bar/(m ³ /h)/m ² 5.7×10^{-6}	gpm/ft ² 5-15	(m ³ /h)/m ² 12-36
M	45	5×10^{-4}	14.1×10^{-6}	5-15	12-36
J	25	45×10^{-4}	1.28×10^{-4}	3-8	7-20
K	18	72×10^{-4}	2.04×10^{-4}	2-7	5-17
S SERIES PSS FILTERS					
S050	AT 99.98% EFFICIENCY ⁽³⁾ 5	psi/gpm/ft ² 0.54	bar/(m ³ /h)/m ² 0.0153	gpm/ft ² 0.5-2	(m ³ /h)/m ² 1.2-4.9
S100	10	0.21	0.0059	0.75-5	1.8-12
S200	20	0.04	0.0011	2.00-7	5.0-17
S350	35	0.01	0.0003	3.0-10	7.0-24
PMM FILTERS					
M020 ⁽⁴⁾	AT 99.98% EFFICIENCY ⁽³⁾ 2	psi/gpm/ft ² 0.87	bar/(m ³ /h)/m ² 0.0246	gpm/ft ² 0.1-0.75	(m ³ /h)/m ² 0.025-1.85
M050 ⁽⁴⁾	5	0.49	0.0138	0.1-0.75	0.25-1.85
M100 ⁽⁴⁾	10	0.28	0.0078	0.2-1	0.5-2.5
M150	15	0.17	0.0048	0.5-3	1.2-7.3
M180	18	0.15	0.0037	0.7-4	1.7-10
M200	20	0.07	0.0020	0.7-4	1.7-10
M250	25	0.02	0.0006	1.0-5	2.5-12
PMF PLEATED FILTERS					
FH025	AT 99.98% EFFICIENCY ⁽³⁾ 2.5	psi/gpm/ft ² 0.194	bar/(m ³ /h)/m ² 0.0055	gpm/ft ² 0.2-0.5	(m ³ /h)/m ² 0.5-1.2
FH050	5	0.050	0.0014	0.5-2.0	1.2-5
FH080	8	0.035	0.001	0.6-3.0	1.5-7
FH100	10	0.020	0.00057	0.75-4.0	1.85-10
FH150	15	0.010	0.00028	1.0-5.0	2.5-12
FH200	20	0.006	0.00017	1.25-7.0	3-17
FH250	25	0.005	0.00014	3.0-8.0	7-20
FH300	30	0.004	0.00011	3.0-10.0	7-24
FH400	40	0.003	0.0001	5.0-15.0	12-36
PROSEP FILTERS					
		1.25"/32mm O.D. ⁽⁵⁾		2"/50mm O.D. ⁽⁵⁾	
	AT 99% EFFICIENCY ⁽³⁾	psi/gpm 10" segment	mbar/lpm 250mm segment	psi/gpm 10" segment	mbar/lpm 250mm segment
Y045	5.0	1.7	50.9	0.8	14.5
Y080	8.0	1.2	21.8	0.5	9.1
Y120	12.0	0.6	10.9	0.3	5.5
Y170	17.0	0.5	9.1	0.2	3.6
		gpm/ft ²		(m ³ /h)/m ²	
		0.5-2.0		1.2-5	
		0.6-3.0		1.5-7	
		0.75-4.0		1.85-10	
		0.8-4.5		2-11	

*Standard cylinder configurations constructed of 316L stainless steel, closed at one end with solid stainless steel, with an appropriate fitting welded to the open end.

(1) The diameter of the largest hard spherical particle that will pass through a filter under specified test conditions. This is an indication of the largest opening in the filter elements.

(2) Pressure drop in psi (bar) obtained by multiplying value shown by actual flow desired in gpm (m³/h), viscosity of liquid in centipoise (if other than 1 cp), all divided by total filtration area (ft² or m²) selected.

(3) Liquid removal efficiency ratings are based on a modified F2 test method and actual particle count data.

(4) Pleated cartridges only.

(5) Pressure drop in psi (bar) obtained by multiplying value shown by actual flow desired in gpm (m³/h), viscosity of liquid in centipoise (if other than 1 cp), all divided by total number of 10" segments.

**OSMONICS**

5951 Clearwater Drive
Minnetonka, Minnesota 55343-8990 USA
(15 miles west of Minneapolis airport)
Phone: 612/933-2277
Fax: 612/933-0141

WATER PURIFICATION, FLUID HANDLING, FILTRATION AND SEPARATION SPECIALISTS SINCE 1969

November 8, 1994

VIA FAX: 303/480-1020 AND MAIL

Mr. Pete Miller
WRIGHT WATER ENGINEERS, INC.
2490 West 26th Ave, Suite 100A
Denver, CO 80211

Re: Reverse Osmosis (RO) System for Radionuclide Reduction

Dear Pete:

Please find enclosed the RO specifications that you requested for a system designed to reduce radionuclide levels and achieve EPA drinking water standards. I have priced out for budgetary purposes the four flow rates that you requested for your proposal:

•100 gpm:	\$125,000
•250 gpm:	\$275,000
•500 gpm:	\$450,000
•1000 gpm:	\$875,000

These budget prices all include prechlorination, multimedia sand filtration sized at 5-7 gpm/f² for suspended solids removal, sodium metabisulfite injection for chlorine removal prior to the RO, 5 μ prefiltration, pH adjustment, reverse osmosis machine(s), and a clean-in-place system for periodic cleaning.


Pete, I received the water analysis you provided, but the hardness alone exceeded the TDS, and I didn't even account for the sodium at 359 mg/L. Once an accurate water analysis becomes available, we would be happy to provide WWE with a projection of the RO product water quality. Preliminary estimates indicate that the system recovery (percentage of feed water ending up as product water) will be 75-80%. At this point, it does not appear that ion exchange or GAC will be necessary to reach your effluent goals. Again, these points can be borne out in the future with a more accurate analysis of the feed water's constituents.

Osmonics represents a sole-source supplier for most components in this proposed system for WWE. We manufacture the multimedia filters, the 5 μ cartridge filters, the RO and CIP units, the pumps, membrane elements, and housings on the RO skid, as well as ion exchange and GAC filters if deemed necessary by the water chemistry.

I will be out of the office the rest of this week, but would welcome the opportunity to discuss this with you in greater detail. I hope this will be helpful to you in your presentation. If immediate questions should arise in the interim, please ask to speak to any Application Engineer in the Engineered Products & Systems Division. We may be reached at 800/848-1750.

Sincerely,

OSMONICS, INC.



Michael P. McDonald
Lead Application Engineer
Engineered Products & Systems

Encl: RO Specifications (Hand-Edited)

mc: Mr. John T. Peichel, OSMONICS, INC., Denver Sales Engineer,
303/438-8605

EQUIPMENT SPECIFICATIONS

DUAL MEDIA FILTER

Automatic backwashable multi-media filter. All PVC piping and placite coated steel tanks are used with no steel or galvanized steel in contact with the water. The filter is typically used on the feedwater entering the OSMO RO unit. Can be operated on water down to pH = 5.0 as well as seawater, depending on filter media. Backwash is automatic off of a 7-day clock.

Manganese greensand makes up the final filtration of this filter with a layer of larger diameter anthracite making up the top layer. The combination of media allows coarse filtration at the top of the bed where it belongs followed by the exceptionally fine filtration of manganese greensand to polish the anthracite filtered water. Coarse, washed, inert gravel is used to support the filter bed and give superior feed and backwash flow distribution. These filters have been engineered to supply the ultimate in filtered water. For feedwater with iron or bacteria, we recommend that our CFS-10X chlorinator be used prior to the filter.

Backwashing of the filter at less than the specified rate will usually result in poor capacity and breakthrough of the turbidity. For the filter to operate properly the backwash must be as indicated. Make certain this flow rate of water is available for 20 minutes continuously. For systems with more than one filter, the filters are sized to allow treatment of service flow while one filter is being backwashed.

Model:	DM-72 (100 gpm), DM-96 (all others)
Quantity:	1,1,2,4 filters respectively for flow rates of 100, 250, 500 and 1,000 gpm

Flows:	
Service:	1.33 times RO product flow rate
Intermittent Service:	2 times service flow
Backwash:	2 times service flow

Dimensions/Weight:	
Height:	108 in
Width:	84, 108 in respectively
Length:	84, 108 in respectively
Side Shell Height:	72 in
Tank Diameter:	72, 96 in respectively
Weight:	8,000/10,000 lb respectively

Electrical Requirement:	115 VAC, 1-phase, 60 Hz
-------------------------	-------------------------

Tank:	
Design Pressure:	100 psig (6.9 bar)
Material:	Carbon Steel
Lining:	Epoxy
Coating:	Epoxy prime, phenolic overcoat
Design:	ASME design, non-stamped

Equipment Specifications
Page 2

Media:	Anthracite Manganese Greensand Support Gravel
Freeboard:	100%
Piping:	
Face Piping:	Schedule 80 PVC
Inlet and Outlet:	IPS Flange
Upper Distributor:	PVC Centered Elbow
Lower Distributor:	PVC Hub and Radial
Valve Type:	Actuated (Diaphragm-operated or Butterfly)

Features:

- Auto-timed stager to control backwash sequence
- Pre- and post-filter pressure gauges
- Drain valve
- Auxiliary contact to receive start/stop signal from system
- Skid-mounted
- Backwash sight glass
- Manway
- Sample and clean-out ports
- Chemical injection pump (optional)
- In-line flow meter (optional)

cont...

Equipment Specifications
Page 3

RO SYSTEM

The RO system produces purified water (permeate) from the feedwater via rejection of organic and inorganic constituents by a semi-permeable membrane.

Model: OSMO-54A

Flow Rates:
Feed: 1.33 times permeate
Permeate: 100, 250, 500, or 1,000 gpm at 77°F (25°C)
Concentrate: 25% of feed
Product Water Recovery: 75-80%
All flow rates are preset at Osmonics' factory.

Quantity: 1,1,1,2 respectively

Prefilters Housing: 304 stainless steel filter housing. The housing holds 7 HYTREX cartridges each and has individual vent and drain valves. Housings will hold cartridges either with knife edge or O-ring seals. Housings are equipped with isolation valves if more than one housing is required.

Cartridges: HYTREX II 5-micron polypropylene, spun-wound depth filters.

Chemical Feed Pumps

Two electrically-operated precision chemical feed pumps. Each feed pump also includes a day tank with injector valve, ceramic weight and foot valve. When used for acid, a pump will be controlled by the pH meter/controller. Pumps are pre-wired at factory. A polyethylene day tank is provided for each chemical feed pump.

High Pressure Pump

TONKAFLO SS multi-stage centrifugal pumps with 316 stainless steel castings and Noryl impellers.

Motors:
Brake Horsepower Required: 30, 75, 150, and 300 Hp respectively
Electrical Requirement: 460 VAC, 3-phase, 60 Hz
Motor Type: TEFC or ODP

Piping:
Feed or Inlet: IPS Flange Connection
Permeate: IPS Flange Connection
Concentrate: IPS Flange Connection
High-Pressure Piping: 304 stainless steel
Low-Pressure Piping: Schedule 80 PVC

cont...

Equipment Specifications

Page 4

Sepralator Housings

Materials of Construction: All 304 stainless steel for extended life and corrosion resistance.

Other Features:

- All housings have side entrance for feed and concentrate to facilitate easy removal of sepralators and simplified construction of the manifolding
- Each housing has a permeate sample port
- Each housing features Osmonics' patented "twist-lock" end assembly to simplify removal and installation of the end caps

Sepralators

OSMO-811-HR(PA) sepralators will be used in this machine. Sepralators come installed in the machine complete with anti-telescoping devices and interconnectors.

Skid and Frame

Skid is heavy-duty painted I-beam steel for ease of conveyance to the point of installation and simplified mounting.

Approximate Dimensions: Length: 22 ft*
 Width: 4.5 ft
 Height: 6.5 ft

Approximate Shipping Weight: 7,500 lb per RO machine

Testing

The RO system will be performance tested with sepralators in place before leaving the factory and the data will be submitted with the instruction manual.

Instrumentation

pH Monitor - Continuously monitors the pH of the feed, controls the acid feed pump, and has adjustable alarm set points.

Conductivity Monitor - Continuously measures permeate conductivity. The monitor includes a temperature-compensated cell.

Flow Meters - Flow meters are included for measurement of permeate, concentrate and total flow rates.

*100 gpm machine has smaller footprint

cont...

Equipment Specifications

Page 5

Pressure Gauges - Two panel-mounted gauges indicate primary and final pressures through sepralator banks. Each sepralator bank has an independent pressure gauge on manifolds. Permeate has in-line pressure gauge. (Differential-pressure gauges and switches to monitor pressure drop across sepralators available on request.) Pre- and post-cartridge filter pressure gauges are mounted in-line.

Thermometer - Measures temperature of solution in sepralators and is mounted in-line. Stainless steel wetted components.

All instrumentation is mounted in easy operator view and completely wired at the factory.

Alarms

The following isolated alarms are included with the system:

TC-85 - Temperature control switch with stainless steel well. Adjustable set point should be set to shut off machine at 85°F (36°C). If machine is designed for high temperatures, this is set 8°F (4°C) over the design temperature.

pH Alarms - High- and low-pH alarms will shut down the machine if the pH is out of range. These set points are controlled through the pH monitor.

High-Temperature Switch - Non-adjustable switch to automatically alarm and shut down the machine if the temperature goes above 110°F (43°C).

High/Low-Flow Switch: Adjustable switch in the feed line after the machine recycle to monitor the total flow in the OSMO machine. Preset at factory. Should flow be outside the control range, the machine will shut down.

Low-Pressure Switch: Adjustable switch in the feed line after the prefilter. Should the pressure be less than setting, the machine will shut down. Ensures a positive pressure to the main pump.

High Permeate Pressure Switch: Adjustable switch mounted in the permeate line. Should the permeate pressure exceed the set point (usually 80 psig, 5.5 bar), the switch will immediately shut down the machine.

- All alarm switches are pre-wired at the factory and tested prior to shipment.
- The switches must be reset with the manual reset button before the system can be restarted after an alarm shut down.
- When the machine is in an alarm condition, both a red alarm light and an audible signal are activated. The audible alarm can be muted by the operator when servicing the machine.

cont...

Equipment Specifications

Page 6

- The electrical panel has five indicators to show which alarm shut down the machine.
- Indicators are red and are set up so that the primary alarm mode will be the only indicator lighted.

Electrical

- All of the controls and electrical components are of NEMA-12 construction and conform to the J.I.C. specifications for "mass-production equipment."
- The master auto-on-off electrical switch, indicator lights, temperature alarm, motor starter, transformer, disconnect switch and relays are pre-wired at Osmonics factory and mounted in a NEMA-12 enclosure. All instrumentation, pressure switches, solenoid valves, and indicator lights are also pre-wired.
- Customer supplies 460 VAC, 3-phase, 60 Hz power to the disconnect in the enclosure.
- Some controls may require a minimum of 60 psig (4.1 bar) clean, dry, oil-free shop air, supplied by the customer. A regulator is on the machine. If air is not available, contact Osmonics for an alternate system.

cont...

Equipment Specifications
Page 7

CLEAN-IN-PLACE (CIP) UNIT

Functional Description: A skid-mounted transfer pump and tank combination to recirculate cleaning solution through the membrane system. Cleaning solution is mixed and heated by recirculation through the RO and CIP system.

Model:	CIP-600C
Tank Capacity:	Sized off feed rate to RO
Pump(s):	TONKAFLO multi-stage centrifugal
Motor(s):	
Type:	TEFC
Power:	10 Hp
Power Required:	460 VAC, 3-phase, 60 Hz
Piping:	Schedule 80 PVC
RO Feed:	IPS Flange Connection
Permeate Return:	IPS Flange Connection
Concentrate Return:	IPS Flange Connection
Tank Fill:	IPS Flange Connection

MPM/kt
8 Nov 94
instruct\equpspc#

WACCO

WATER CONTROL CORPORATION

2696 S. COLORADO BLVD. #580-2

DENVER, CO 80222

PHONE (303) 757-3522

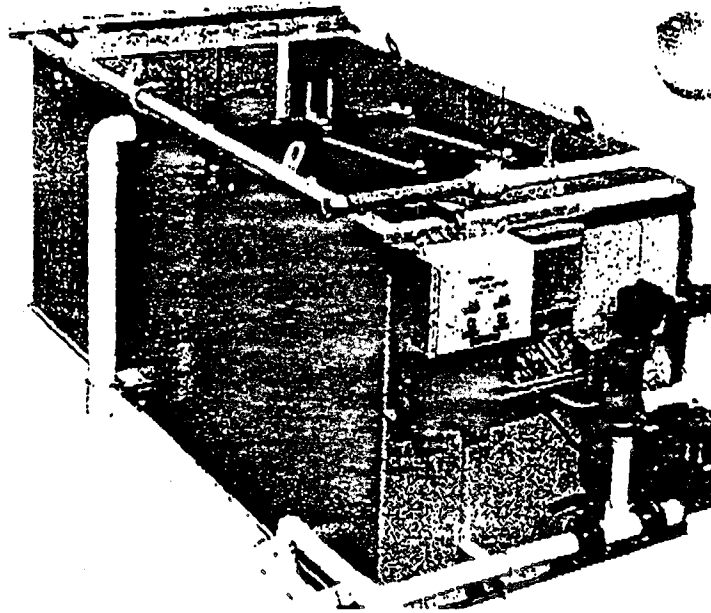
FAX (303) 757-3518

FAX TRANSMITTAL

TO: Pete MillerDATE: 11-9-94COMPANY: Wright Water EngrsFAX NO: 303/480-10203 No. of pages, including this cover sheet. If you do not receive all pages, please call 303/757-3522.FROM: Jack SimpsonREF: Rocky Flats

Desired Flow	Plant Capability	Plant Designation	Budget Pricing
100 GPM	100 GPM	WB-133A	\$56,000
250 GPM	260 GPM	1/2 AQ-112B	\$115,000
500 GPM	520 GPM	AQ-112B	160,600
1000 GPM	1050 GPM	1 1/2 AQ-150B	220,000

Technical data sheets herewith.



WATER BOY® TECHNICAL DATA SHEET

PARAMETERS		UNITS	WB-14	WB-27	WB-82	WB-133A
Nominal Flow GPD			14,400 (10 GPM)	38,800 (20 GPM)	88,400 (50 GPM)	144,000 (100 GPM)
Shipping Dimensions	Length (ft)		7'-0"	8'-10"	8'-8"	16'-0"
	Width (ft)		4'-0"	4'-8"	7'-7"	7'-6"
	Height (ft)		5'-0"	6'-10"	7'-5"	7'-5"
Weights	Shipping (lbs.)		3,400	3,500	8,000	14,600
	Operating (lbs.)		5,900	11,000	24,000	40,000
Base Pad Design	Pounds/ft²		800	800	800	800
Backwash Volume	Gallons/Holding Tank		650	950	2,400	3,800
Overhead Clearance	Minimum (ft)		4'-0"	4'-0"	4'-0"	4'-0"
Pipe Connections	Inlet (in.)		1½	1	2	2½
	Effluent (in.)		1½	1	2	2½
	Backwash (in.)		combined w/effluent	2	4	4
	Waste/Overflow (in.)		6	6	8	8
Process Components	Flocculation Volume (ft³)		12	19	80	168
	Tube Settler Overflow Rate (GPD/ft²)		100	170	180	130
	Filter Area (ft²)		2	4	12	20
	Pumps	Effluent	½ hp, 10 gpm	½ hp, 20 gpm	1 hp, 60 gpm	2 hp, 100 gpm
		Backwash	½ hp, 40 gpm	1 hp, 80 gpm	7 ½ hp, 220 gpm	10 hp, 360 gpm
	Controls		Automatic	Automatic	Automatic	Automatic
	Chemical Feed	Alum	30 gal. tank 24 gpd pump	30 gal. tank 24 gpd pump	50 gal. tank 60 gpd pump	100 gal. tank 108 gpd pump
		Polyelectrolyte	30 gal. tank 24 gpd pump	30 gal. tank 24 gpd pump	50 gal. tank 24 gpd pump	50 gal. tank 67 gpd pump
		Hypochlorite	30 gal. tank 24 gpd pump	30 gal. tank 24 gpd pump	50 gal. tank 24 gpd pump	50 gal. tank 31 gpd pump
		Mixers	1750 rpm ½ hp, 115V, 1Ø	1750 rpm ½ hp, 115V, 1Ø	1750 rpm ½ hp, 115V, 1Ø	1750 rpm ½ hp, 115V, 1Ø
		Pump	½ hp, 115V, 1Ø	½ hp, 115V, 1Ø	½ hp, 115V, 1Ø	½ hp, 115V, 1Ø
Finish	Interior		sandblast and immersion grade finish coating			
	Exterior		sandblast and immersion grade finish coating			
Electrical	Load Center		230V, 60 Hz, 1Ø 40 amps	230V, 60 Hz, 1Ø 40 amps	230V, 60 Hz, 3Ø 70 amps	230V, 60 Hz, 3Ø 70 amps
	Pumps		115/230V, 60 Hz, 1Ø	115/230V, 60 Hz, 1Ø	230/460V, 60 Hz, 3Ø	230/460V, 60 Hz, 3Ø

modular aquatics

Technical Data Sheet

**microfloc
products**

	MODEL	AQ-70B	AQ-112B	AQ-150B	AQ-300B
NOMINAL FLOW	GPM	350	520	700	1400
INLET PRESSURE REQUIRED	MIN. FEET OF WATER FROM BASE OF UNIT	15	15	15	15
	MAX. FEET OF WATER	45	45	45	45
DIMENSIONS (PER TANK)	LENGTH	23 ft. 10 in.	26 ft. 7 in.	29 ft. 3 in.	39 ft. 11 in.
	WIDTH	6 ft. 9 in.	8 ft. 4 in.	9 ft. 9 in.	11 ft. 11 in.
	HEIGHT	8 ft. 1 in.	8 ft. 1 in.	8 ft. 1 in.	10 ft. 1 in.
WEIGHTS PER TANK	SHIPPING	10,500 lbs.	11,500 lbs.	14,700 lbs.	27,500 lbs.
	OPERATING	80,500 lbs.	114,500 lbs.	155,250 lbs.	318,000 lbs.
PIPE SIZES (ALL PIPING BY OTHERS)	INLET	4 inches	6 inches	6 inches	8 inches
	OUTLET	8 inches	10 inches	12 inches	12 inches
	BACKWASH	6 inches	8 inches	8 inches	10 inches
	SURFACE WASH	2 inches	2 inches	2 inches	2 inches
	WASTE	8 inches	10 inches	12 inches	14 inches
	OVERFLOW	8 inches	10 inches	12 inches	14 inches
VALVES (A) AUTOMATIC (M) MANUAL	INLET RATE SET	6 inches (A)	6 inches (A)	6 inches (A)	10 inches (A)
	INFLUENT ISOLATION	4 inches (M)	6 inches (M)	6 inches (A)	8 inches (A)
	EFFLUENT	4 inches (A)	4 inches (A)	6 inches (A)	8 inches (A)
	BACKWASH	6 inches (A)	8 inches (A)	8 inches (A)	10 inches (A)
	BACKWASH RATE SET	6 inches (M)	8 inches (M)	8 inches (M)	10 inches (M)
	WASTE	8 inches (A)	10 inches (A)	12 inches (A)	14 inches (A)
	SURFACE WASH	2 inches (A)	2 inches (A)	2 inches (A)	2 inches (A)
PUMPS	EFFLUENT	3 HP. 175 GPM	5 HP. 260 GPM	SEE NOTE No. ①	
	SURFACE WASH	3 HP. 25 GPM	3 HP. 29 GPM	SEE NOTE No. ①	
	BACKWASH	10 HP. 630 GPM	15 HP. 1000 GPM	SEE NOTE No. ①	
FLOCCULATION COMPARTMENT	DETENTION TIME MINUTES	20	20	20	20
	DRIVE MOTOR	¼ HP	¼ HP	¼ HP	¼ HP
TUBE SETTLING COMPARTMENT	OVERFLOW RATE GPD/FT. ²	151	178	193	253
FILTER COMPARTMENT	TOTAL AREA (2 FILTERS) SQ. FT.	70	104	140	280
	RATE GPM/FT. ²	5	5	5	5
	MEDIA	30 in. MIXED MEDIA	30 in. MIXED MEDIA	30 in. MIXED MEDIA	30 in. MIXED MEDIA
	GRAVEL	18½ inches	18½ inches	18½ inches	18½ inches
	UNDERDRAIN	PIPE LATERAL	PIPE LATERAL	PIPE LATERAL	PIPE LATERAL
	SURFACE WASH RATE	25 GPM @ 60 psi	29 GPM @ 60 psi	43 GPM @ 60 psi	65 GPM @ 60 psi
	BACKWASH RATE ④	525 GPM	780 GPM	1050 GPM	2100 GPM
	WATER REQUIRED ⑤ FOR ONE BACKWASH GALLONS	3775	5576	7522	14,960
	INSTANTANEOUS WASTE FLOW GPM ①	1050	1475	1900	3250
CHEMICAL FEED	ALUM	TANK	200 Gallon	400 Gallon	500 Gallon
		PUMP	240 GPD	480 GPD	480 GPD
		MIXER	¼ HP. 115 V	½ HP. 115 V	½ HP. 115 V
	POLY	TANK	100 Gallon	200 Gallon	400 Gallon
		PUMP	Two—24 GPD	Two—50 GPD	Two—120 GPD
		MIXER	¼ HP. 115 V	¼ HP. 115 V	¼ HP. 115 V
CONTROLS	TYPE	Automatic	Automatic	Automatic	Automatic
	CONTROL PANEL	3 ft. x 2.5 ft. x 10 in.	3 ft. x 2.5 ft. x 10 in.	3 ft. x 2.5 ft. x 10 in.	3 ft. x 2.5 ft. x 10 in.
ELECTRICAL	CONTROL PANEL	120 V. 60 Hz. 1Ø	120 V. 60 Hz. 1Ø	120 V. 60 Hz. 1Ø	120 V. 60 Hz. 1Ø
	PUMPS	240 V. 60 Hz. 3Ø	240 V. 60 Hz. 3Ø	240 V. 60 Hz. 3Ø	240 V. 60 Hz. 3Ø
COMPRESSED AIR REQUIREMENTS	CFM @ PSIG	6.5 @ 80	6.5 @ 80	6.5 @ 80	6.5 @ 80
FINISH	INTERNAL	FINISH PROTECTIVE COATING SUITABLE FOR POTABLE WATER			
	EXTERNAL	SANDBLAST AND UNIVERSAL PRIMER (BARE TANK BOTTOM) ①			

THRU ① SEE NOTES ON BACK SIDE OF THIS SHEET

BULLETIN No. KS 5-58-9

APPENDIX C

**WATER QUALITY SUMMARY STATISTICS
1991-1994, ROCKY FLATS
ENVIRONMENTAL TECHNOLOGY SITE**

Table 4-5 (Continued)
Rocky Flats Stormwater Quality Data Summary
Water Years 1991-1993

Total Metals (ug/L)*	GS12							GS13						
	Sample #	Max Value	Min Value	Avg Value	# < MDL*	Exceeds	Standard**	Sample #	Max Value	Min Value	Avg Value	# < MDL*	Exceeds	Standard**
SELENIUM	1	2.5	2.5	2.50	1	0	0	10	48	0.8	23.25	19	10	10
SILICON	1	0	0	0.00	0	0	0	20	7490	0	2091.50	0	0	0
SILVER	1	5	5	5.00	1	0	0	50	7	1.45	4.84	20	0	50
SODIUM	1	27000	27000	27000.00	0	0	0	21	49800	13500	24006.52	0	0	0
STRONTIUM	0				0	0	0	10	572	141	234.90	5	0	0
THALLIUM	1	5	5	5.00	1	1	0.012	20	191	0.7	85.06	20	20	0.012
TIN	1	100	100	100.00	1	0	0	10	100	5.2	27.54	10	0	0
VANADIUM	0				0	0	0	10	16.7	7	11.11	10	0	0
ZINC	1	10	10	10.00	1	0	0	350	340	3.6	93.96	2	0	350
GS12														
GS13														
Radiocnucleides (pCi/L)	Sample #	Max Value	Min Value	Avg Value	Exceeds	Standard**		Sample #	Max Value	Min Value	Avg Value	Exceeds	Standard**	
AMERICIUM-241	1	0.011	0.011	0.01	0	0.05		10	0.093	0.002	0.04	4	0.05	
CESIUM-137	0				0	0		10	0.26	-0.005	0.08	0		
CURIUM-244	0				0	0		3	0.028	-0.012	0.01	0		
GROSS ALPHA	1	2.71	2.71	2.71	0	11		16	7	-0.37	4.08	0	11	
GROSS BETA	1	8.5	8.5	8.50	0	10		14	10	0.63	5.90	0	10	
NEPTUNIUM-237	0				0	0		2	0.041	0.016	0.03	0		
PLUTONIUM-239	1	0.012	0.012	0.01	0	0.05		10	0.285	-0.003	0.06	7	0.05	
RADIUM-226	0				0	5		2	0.16	0.11	0.14	0	5	
RADIUM-228	0				0	5		1	1.4	1.4	1.40	0	5	
STRONTIUM-90	0				0	0		11	0.83	-0.009	0.33	0		
THORIUM-232	0				0	0		1	0.39	0.39	0.39	0	0	
TRITIUM	1	147.1	147.1	147.10	0	500		3	0.89	0.01	0.28	0	0	
URANIUM-233	0				0	10		8	140.55	-31	84.96	0	500	
URANIUM-234	0				0	10		7	2.773	0.499	0.99	0	10	
URANIUM-235	1	0.06522	0.06522	0.10	0	10		1	1.1	1.1	1.10	0	10	
URANIUM-238	1	1.4	1.4	1.40	0	10		10	0.44	-0.005	0.06	0	10	
GS12														
GS13														
Water Quality (mg/L)	Sample #	Max Value	Min Value	Avg Value	Exceeds	Standard**		Sample #	Max Value	Min Value	Avg Value	Exceeds	Standard**	
ALKALINITY				No Data Available				7	246.6	85.2	106.84	0		
CARBONATE				No Data Available				7	7.7	0	1.10	0		
CHLORIDE				No Data Available				7	49.6	16.6	26.44	0		
CONDUCTIVITY				No Data Available				7	706	216	302.00	0		250
FLUORIDE				No Data Available				7	0.94	0.5	0.65	0		
NITRATE				No Data Available				8	1.39	0.78	0.97	0		2
pH				No Data Available				7	7.9	6.9	7.43	0		10
SULFATE				No Data Available				7	53.1	13.1	23.96	0		6.5-9.0
TOTAL DISSOLVED SOLIDS				No Data Available				7	499	157	241.00	1		250
TOTAL SUSPENDED SOLIDS				No Data Available				7	233	4	83.00	0		

Source: EOLB, 1994. Event-related Surface Water and Sediment Sampling Data for Water Years 1991-1993. Provided by Greg Wetzel, EOLB, Surface Water Division.

* The test method used for metals analysis was inductively coupled plasma atomic emission spectroscopy (ICP-AES), unless otherwise noted. This test method has relatively high detection limits; therefore, the majority of exceedances noted are due to artificially inflated values calculated based on one-half of the method detection limit (MDL).

** No value is presented for these analytes without WQCC numeric standards.

*** The site-specific WQCC standard for dissolved beryllium was also used for total beryllium because no site-specific total beryllium standard exists.

Table 4-5 (Continued)
Rocky Flats Stormwater Quality Data Summary
Water Years 1991-1993

Total Metals (µg/L)*	GS09						GS10							
	Sample #	Max Value	Min Value	Avg Value	# < MDL*	Exceeds	Standard**	Sample #	Max Value	Min Value	Avg Value	# < MDL*	Exceeds	Standard**
NICKEL	0	20	5.0	14.93	0	0	200	31	35.2	9.35	14.24	24	0	200
POTASSIUM	0	11700	2500	8424.44	2	0		31	8750	875	3605.45	19	0	
SELENIUM	0	48	0.35	30.15	0	0	10	29	48	0.35	23.92	29	18	10
SILICON	7	7330	0	2444.71	0	0		27	9900	0	1710.11	1	0	
SILVER	0	7	2.4	5.27	0	0	50	30	6.6	1.05	4.81	26	0	50
SODIUM	0	35000	7770	18098.07	0	0		31	55000	343	20582.61	3	0	
STRONTIUM	0	182	128	154.83	0	0		19	433	9	182.83	11	0	
THALLIUM	0	191	0.9	105.06	0	0	0.012	31	191	0.45	93.39	30	31	0.012
TIN	0	100	10	34.47	0	0		31	100	4.7	22.92	30	0	
VANADIUM	0	20.9	7	12.13	0	0		19	59.2	6	23.38	19	0	
ZINC	0	308	37.4	138.14	0	0	350	31	1180	7	331.80	4	12	350
Radionuclides (pCi/L)	GS09						GS10							
	Sample #	Max Value	Min Value	Avg Value	Exceeds	Standard**	Sample #	Max Value	Min Value	Avg Value	Exceeds	Standard**		
AMERICIUM-241	0	0.24	-0.021	0.09	0	0.05	22	0.45	-0.003073	0.15	16	0.05		
CESIUM-137	1	0.72	0.72	0.72	0		8	0.34	0.024	0.14	0			
CURIUM-244	1	0.008	0.008	0.01	0		3	0.018	-0.004	0.01	0			
GROSS ALPHA	7	7	0	3.34	0	11	23	25	1.6	7.65	4	11		
GROSS BETA	7	21.48	0	13.18	1	18	22	21.5	2	10.34	3	19		
NEPTUNIUM-237	1	0.025	0.025	0.03	0		3	0	-0.009	0.00	0			
PLUTONIUM-239	0	0.125	0.028	0.07	0	0.05	26	0.58	0.005	0.12	13	0.05		
RADIUM-226	0	0	0	0	0	6	3	0.47	0.38	0.43	0	5		
RADIUM-228	0	0	0	0	0	5	1	2.7	2.7	2.70	0	5		
STRONTIUM-90	1	0.4	0.4	0.40	0		7	0.42	-0.74	0.07	0			
THORIUM-232	1	0.73	0.73	0.73	0	6	1	0.27	0.27	0.27	0	6		
TITANIUM	2	0	-72	-36.00	0	900	3	0.91	0.19	0.89	0	80		
URANIUM-233	0	0.547	0.1435	0.30	0	10	11	276.3	-150	31.34	0	500		
URANIUM-234	0	0	0	0	0	10	15	55	0.26	4.27	1	10		
URANIUM-235	0	0.034	-0.01	0.01	0	10	0	0	0	0	0	10		
URANIUM-238	0	0.88	0.061	0.33	0	10	28	0.29	-0.044	0.04	0	10		
Water Quality (mg/L)	GS09						GS10							
	Sample #	Max Value	Min Value	Avg Value	Exceeds	Standard**	Sample #	Max Value	Min Value	Avg Value	Exceeds	Standard**		
ALKALINITY	0	112.7	39.5	70.64	0		14	116	43.8	88.32	0			
CARBONATE	0	0	0	0.00	0		15	10	0	0.07	0			
CHLORIDE	0	28.4	0.91	18.36	0	250	15	44.5	12.9	20.85	0	250		
CONDUCTIVITY	0	578	301	408.00	0		14	674	160	358.93	0			
FLUORIDE	0	40.8	0.5	8.81	1	2	15	2.5	0.23	0.75	1	2		
NITRATE	3	2.78	1.88	2.08	0	10	12	4.56	1.03	1.84	0	10		
PH	0	7.5	6.8	7.20	0	6.5-9.0	14	7.9	6.51	7.13	0	6.5-9.0		
SULFATE	0	38.9	9.3	34.54	0	250	15	121	14.3	50.09	0	250		
TOTAL DISSOLVED SOLIDS	0	319	165	228.00	1	280	15	440	132	275.00	8	250		
TOTAL SUSPENDED SOLIDS	0	160	28	86.80	0		15	550	13	194.47	0			

Source: 2010, 1994, Event-Related Surface Water and Sediment Sampling Data for Water Years 1991-1993. Provided by Greg Wehner, 2010, Surface Water Division.

* The test method used for metals analyses was inductively coupled plasma atomic emission spectroscopy (ICP-AES), unless otherwise noted. This test method has relatively high detection limits; therefore, the majority of exceedances noted are due to artificially inflated values calculated based on one-half of the method detection limit (MDL).

** No value is presented for these analytes without WQCC numeric standards.

*** The site-specific WQCC standard for dissolved beryllium was also used for total beryllium because no site-specific total beryllium standard exists.

TABLE 4-12
(page 1 of 6)

RADIONUCLIDES SUMMARY STATISTICS

Location	Analyte	Segment 5 Standard (pCi/L)	Sample Size	Samples Exceeding Standard Number (Pct)	Mean Concentration (pCi/L)	Standard Deviation (pCi/L)	85th Percentile (pCi/L)	Minimum (pCi/L)	Maximum (pCi/L)
A1	GROSS ALPHA	11	16	1 (6.2%)	7.983	4.259	9.000	3.7230	22.000
A1	GROSS BETA	19	17	0 (0.0%)	12.243	2.580	14.000	6.7000	17.690
A1	AMERICIUM-241	0.05	9	1 (11.1%)	0.019	0.021	0.037	0.0010	0.064
A1	PLUTONIUM-239/240	0.05	9	0 (0.0%)	0.025	0.012	0.035	0.0090	0.042
A1	URANIUM-233/234	10	9	0 (0.0%)	2.823	0.643	3.500	2.0000	4.000
A1	URANIUM-238	10	9	0 (0.0%)	4.310	1.056	5.200	2.3000	5.700
A2	GROSS ALPHA	11	18	2 (11.1%)	6.763	2.778	9.000	3.1000	13.040
A2	GROSS BETA	19	19	1 (5.3%)	12.056	4.246	14.000	4.0000	26.230
A2	AMERICIUM-241	0.05	11	1 (9.1%)	0.013	0.018	0.019	-0.0090	0.063
A2	PLUTONIUM-239/240	0.05	11	0 (0.0%)	0.019	0.010	0.032	0.0000	0.035
A2	URANIUM-233/234	10	11	0 (0.0%)	3.558	0.892	4.878	1.8170	4.952
A2	URANIUM-238	10	11	0 (0.0%)	4.778	1.474	6.516	2.2540	6.929
B1	GROSS ALPHA	11	16	1 (6.2%)	3.603	3.323	5.000	0.6400	15.000
B1	GROSS BETA	19	17	0 (0.0%)	7.386	2.087	9.600	4.8480	13.000
B1	AMERICIUM-241	0.05	8	3 (37.5%)	0.085	0.145	0.075	0.0060	0.440
B1	PLUTONIUM-239/240	0.05	9	3 (33.3%)	0.058	0.047	0.100	0.0180	0.160
B1	URANIUM-233/234	10	9	0 (0.0%)	1.407	0.648	2.300	0.4200	2.400
B1	URANIUM-238	10	9	0 (0.0%)	1.431	0.503	1.853	0.7400	2.200
B2	GROSS ALPHA	11	16	0 (0.0%)	4.045	2.933	7.000	0.0840	10.000
B2	GROSS BETA	19	17	1 (5.9%)	8.136	3.588	9.100	5.1000	21.110
B2	AMERICIUM-241	0.05	8	0 (0.0%)	0.025	0.018	0.045	0.0050	0.046
B2	PLUTONIUM-239/240	0.05	9	5 (55.6%)	0.071	0.053	0.130	0.0120	0.140
B2	URANIUM-233/234	10	9	0 (0.0%)	1.825	0.838	2.700	0.7900	3.100
B2	URANIUM-238	10	9	0 (0.0%)	1.531	0.690	2.300	0.7500	2.800

POND A3 TOTAL RADIONUCLIDES SUMMARY STATISTICS

Analyte	Segment 4 Standard (pCi/L)	Sample Size	Samples Not Exceeding Standard		Samples Exceeding Standard		Mean (pCi/L)	85th Percentile (pCi/L)	Concentration	
			Number	(Pct)	Number	(Pct)			Min. (pCi/L)	Max. (pCi/L)
AMERICIUM-241	0.05	9	9 (100.0%)		0 (0.0%)		0.0147	0.03	0.0045	0.034
CESIUM-137	None	9	9 (100.0%)		N/A		0.049	0.17	-0.092	0.37
CURTIUM-244	None	8	8 (100.0%)		N/A		0.0009	0.003	-0.003	0.005
GROSS ALPHA	11	26	26 (100.0%)		0 (0.0%)		3.6521	4	2	5.63
GROSS BETA	19	26	26 (100.0%)		0 (0.0%)		5.8648	7	3	8.709
NEPTUNIUM-237	None	1	1 (100.0%)		N/A		0.054	0.054	0.054	0.054
PLUTONIUM-239/240	0.05	8	8 (100.0%)		0 (0.0%)		0.0088	0.017	-0.004	0.0247
STRONTIUM-89/90	8	9	9 (100.0%)		0 (0.0%)		0.6406	0.99	0.14	2.05
THORIUM-230/232	60	1	1 (100.0%)		0 (0.0%)		0.029	0.029	0.029	0.029
TRITIUM	500	17	17 (100.0%)		0 (0.0%)		46.529	168.6	-116	203.1
URANIUM-233/234	10	9	9 (100.0%)		0 (0.0%)		1.7689	2.272	1.3	2.748
URANIUM-235	10	9	9 (100.0%)		0 (0.0%)		0.0892	0.15	0	0.2255
URANIUM-238	10	9	9 (100.0%)		0 (0.0%)		2.6268	3.427	1.7	3.714

TABLE 4-12
(page 3 of 6)

POND A4 TOTAL RADIONUCLIDES SUMMARY STATISTICS

Analyte	Segment 4 Standard (pCi/L)	Sample Size	Samples Not		Samples		Mean (pCi/L)	85th Percentile (pCi/L)	Concentration	
			Exceeding Standard Number (Pct)	Exceeding Standard Number (Pct)	Exceeding Standard Number (Pct)	Exceeding Standard Number (Pct)			Min. (pCi/L)	Max. (pCi/L)
AMERICIUM-241	0.05	38	37 (97.4%)	1 (2.6%)	1 (2.6%)	1 (2.6%)	0.0056	0.01	-0.002	0.067
CESIUM-137	None	26	26 (100.0%)	N/A	N/A	N/A	0.053	0.23	-0.42	0.6864
CURIUM-244	None	13	13 (100.0%)	N/A	N/A	N/A	0.0003	0.0058	-0.007	0.0076
GROSS ALPHA	11	102	102 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1.8971	3	-0.6	6.16
GROSS BETA	19	102	102 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	9.0649	11	0	18
NEPTUNIUM-237	None	3	3 (100.0%)	N/A	N/A	N/A	0.0247	0.033	0.01	0.033
PLUTONIUM-239/240	0.05	39	38 (97.4%)	1 (2.6%)	1 (2.6%)	1 (2.6%)	0.0054	0.013	-0.004	0.067
STRONTIUM-89/90	6	28	28 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0.396	0.63	0.13	1.625
THORIUM-230/232	60	4	4 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0.0701	0.2905	-0.047	0.2905
TRITIUM	500	123	123 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	45.256	180	-794.6	294
URANIUM-233/234	10	39	39 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1.039	1.5	0.4061	2.889
URANIUM-235	10	39	39 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0.0682	0.11	-0.01	0.3254
URANIUM-238	10	39	39 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1.1662	1.6	0.37	2.889

TABLE 4-12
(page 4 of 6)

POND B5 TOTAL RADIONUCLIDES SUMMARY STATISTICS

Analyte	Segment 4 Standard (pCi/L)	Sample Size	Samples Not Exceeding Standard Number (Pct)	Samples Exceeding Standard Number (Pct)	Mean (pCi/L)	85th Percentile (pCi/L)	Concentration Min. (pCi/L)	Max. (pCi/L)
AMERICIUM-241	0.05	24	24 (100.0%)	0 (0.0%)	0.0089	0.022	-0.004	0.0274
CESIUM-137	None	19	19 (100.0%)	N/A	0.1012	0.3101	-0.21	0.79
CURIUM-244	None	14	14 (100.0%)	N/A	0.0035	0.0027	-0.012	0.063
GROSS ALPHA	11	81	81 (100.0%)	0 (0.0%)	1.871	3	-0.1	9
GROSS BETA	19	81	81 (100.0%)	0 (0.0%)	9.4978	12	-14	15
NEPTUNIUM-237	None	3	3 (100.0%)	N/A	0.0457	0.084	0.022	0.084
PLUTONIUM-239/240	0.05	24	24 (100.0%)	0 (0.0%)	0.0096	0.022	-0.002	0.035
STRONTIUM-89/90	8	20	20 (100.0%)	0 (0.0%)	0.193	0.415	-0.184	0.75
THORIUM-230/232	60	4	4 (100.0%)	0 (0.0%)	-0.02	0.058	-0.149	0.056
TRITIUM	500	106	106 (98.1%)	2 (1.9%)	89.566	194.87	-205	1200
URANIUM-233/234	10	24	24 (100.0%)	0 (0.0%)	0.8044	1.1	0.24	1.6
URANIUM-235	10	24	24 (100.0%)	0 (0.0%)	0.0332	0.082	-0.021	0.14
URANIUM-238	10	24	24 (100.0%)	0 (0.0%)	0.6942	0.88	0.26	1.3

TABLE 4-12
(page 6 of 6)

POND C2 TOTAL RADIONUCLIDES SUMMARY STATISTICS

Analyte	Segment 4 Standard (pCi/L)	Sample Size	Samples Not Exceeding Standard		Mean (pCi/L)	85th Percentile (pCi/L)	Concentration	
			Number	(Pct)			Min. (pCi/L)	Max. (pCi/L)
AMERICIUM-241	0.05	28	28 (100.0%)	0 (0.0%)	0.0104	0.017	-0.002	0.0489
CESIUM-137	None	22	22 (100.0%)	N/A	0.0617	0.1931	-0.22	0.51
CURIUM-244	None	11	11 (100.0%)	N/A	-0.005	0.004	-0.054	0.0109
GROSS ALPHA	7	88	88 (100.0%)	0 (0.0%)	2.7731	4	-0.39	6
GROSS BETA	5	88	5 (5.7%)	83 (94.3%)	7.2239	8	-8.1	35.3
NEPTUNIUM-237	None	2	2 (100.0%)	N/A	0.0475	0.095	0	0.095
PLUTONIUM-239/240	0.05	27	21 (77.8%)	6 (22.2%)	0.0303	0.0541	0.002	0.13
STRONTIUM-89/90	8	23	23 (100.0%)	0 (0.0%)	0.4136	0.67	0	0.84
THORIUM-230/232	60	3	3 (100.0%)	0 (0.0%)	0.1047	0.233	-0.005	0.233
TRITIUM	500	106	105 (99.1%)	1 (0.9%)	42.162	150	-221	585.13
URANIUM-233/234	5	27	27 (100.0%)	0 (0.0%)	1.1296	1.6	0.066	2
URANIUM-235	5	27	27 (100.0%)	0 (0.0%)	0.1054	0.15	0	0.62
URANIUM-238	5	27	27 (100.0%)	0 (0.0%)	1.2764	1.954	0.003	2.6

TABLE 4-12
(page 6 of 6)

RADIONUCLIDES SUMMARY STATISTICS

Location	Analyte	Segment 5 Standard (pCi/L)	Sample Size	Samples Exceeding Standard Number (Pct)	Mean Concentration (pCi/L)	Standard Deviation (pCi/L)	85th Percentile (pCi/L)	Minimum (pCi/L)	Maximum (pCi/L)
SV098	GROSS ALPHA	11	22	0 (0.0%)	1.658	1.586	3.100	-0.6700	6.700
SV098	GROSS BETA	19	22	2 (9.1%)	13.414	10.528	12.690	7.9000	59.260
SV098	AMERICIUM-241	0.05	20	1 (5.0%)	0.009	0.017	0.015	-0.0030	0.075
SV098	PLUTONIUM-239/240	0.05	20	0 (0.0%)	0.005	0.007	0.009	-0.0004	0.023
SV098	URANIUM-233/234	10	14	0 (0.0%)	1.077	0.292	1.316	0.7030	1.594
SV098	URANIUM-238	10	14	0 (0.0%)	1.015	0.342	1.246	0.6140	1.964

Table 4-19

Western Cynk - Segment 3 standards. ** Western Cynk - Segment 4 standards

1) Standards used in comparison with standards provided are consistent with the AUJGU identified in this document. When available, Segment 4 (WQCC 4) means standards for Western and Western Canada were used. When the standards between Western and Western Cynk differed, both were provided in the list below. "Western/Canadian" DOE derived concentrations (DOCs) were used as a dual comparison for selected substances with WQCC standards. When no segment specific standards were available, non-DOE standards were used. "NA" represents analyses with no applicable WQCC standards. PQ - practical quantification limit.

2) Organic were tested in the Landfill Test standards. When chemical and toxic values were available, chemical (DOCs) values were chosen. The only non-halide organics detected are identified on the table. In comparison also detected is the

3) WQCC site-specific standard for dioxin was used for comparison because no site-specific standard for total benzofuran exists.

Abstract

APPENDIX D

INTERVIEWS AND PHONE CONTACTS

**APPENDIX D
INTERVIEWS AND PHONE CONTACTS**

McDonald, Fred
No Title Given
Westinghouse - Hanford
(509) 372-2962
Re: 200 Area ETF

Storder, Bob
Engineer
Westinghouse - Hanford
(509) 372-3452
Re: Non rad WWTP ("300 Plant")
wastewater treatment

Williams, Janice
Project Manager
Westinghouse - Hanford
(509) 373-4967
Re: 200 Area ETF Delisting Petition

Bryson, Dana
No Title Given
Westinghouse - Hanford
(509) 372-0738
Re: 200 Area ETF, groundwater treatment

Diener, Glenn
Engineer
Savannah River
(803) 725-2774
Re: Waste Water Treatment Facility

Cellan, Roy
Manager of Reclamation
Homestake Mining Co. (Grants, NM)
(505) 287-4456
Re: Groundwater remediation for Uranium

Gomez, Steve
No Title Given
Los Alamos National Lab
(505) 667-4301
Re: Liquid Effluent Treatment Facility

Hoffman, George
Hydrologist (for Homestake Mining)
(307) 266-6597
Re: HMC's groundwater treatment system
performance

Srinivasan, Chino
No Title Given
Argonne National Laboratory
(708) 252-9829
Re: Bench scale testing of radionuclide
removal for Rocky Flats

Gatchett, Annette
Project Manager
EPA SITE Program
(513) 569-7697
SITE tests at Rocky Flats

Poeton, Rick
No Title Given
EPA - Region 10
(206) 553-8633
Re: Nuclear Power facilities operating data
for WWTP's

Moss, David
Facilities Manager
Los Alamos National Lab
(505) 667-4301
Re: Liquid Effluent Treatment Facility,
improvements

901-004V460cb\Appendix.A

ACKNOWLEDGEMENTS

This report was prepared for Mr. Edward J. Moritz P. E., Surface Water Group, EG&G Rocky Flats Inc., under Task Order MTS 225468001KG/AD3. Principal author and project manager for this report was Mr. Eric W. Mende P. E., Wright Water Engineers Inc. (WWE), under the general guidance of Mr. Frank J. Blaha P. E., WWE, overall program manager for Master Task Subcontract assignments at the Rocky Flats Environmental Technology Site.

Initial internal peer review was provided by Mr. Jonathan Jones P. E., WWE, and Dr. F. Robert McGregor P. E., WWE. EG&G review was performed by Mr. Edward J. Moritz P. E., Dr. Keith Motyl, and Mr. Craig Hoffman. Final peer review was performed by Mr. Merlyn Boss, and Mr. Dale Bokowski. The authors gratefully acknowledge the input, suggestions, review, and other contributions of Mssgrs. Moritz, Blaha, Jones, McGregor, Motyl, Hoffman, Boss, and Bokowski.

Eric W. Mende

Date

11-10-94

Eric W. Mende P. E.

Project Manager

Frank J. Blaha

Date

11/10/94

Frank J. Blaha P. E.

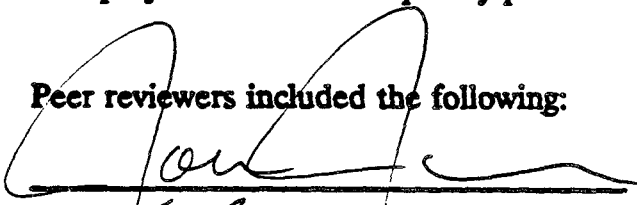
Program Manager

**PEER REVIEW NOTICE
MEMO TO CENTRAL PROJECT FILE**

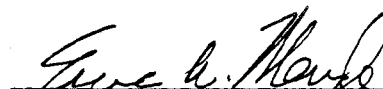
Project Title : Technology Assessment for Radionuclide Removal
Client: Rocky Flats - EG+G
Project No. 901 004 460

This project has been adequately peer reviewed according to good professional standards.

Peer reviewers included the following:


Robert McGregor

The above listed individuals met as a group to discuss the project scope, objectives and results and opinions were offered.

 8-19-94
Project Manager **Date**

- (1) Peer review is represented by at least two other professionals meeting for as long as necessary to review and discuss a draft report or other work product.
- (2) Work product is not WWE work product without a peer review.
- (3) Appraisals must be peer reviewed by individuals who have completed the ethics and standards course.

**PEER REVIEW NOTICE
MEMO TO CENTRAL PROJECT FILE**

Project Title : Technology Assessment for Radionuclide Removal
Client: EG&G Rocky Flats
Project No. 901-004.460

This project has been adequately peer reviewed according to good professional standards.

Peer reviewers included the following:

Dale L. Bokowski 11/01/94
Dale Bokowski Date

Merlyn Boss 11/1/94
Merlyn Boss Date

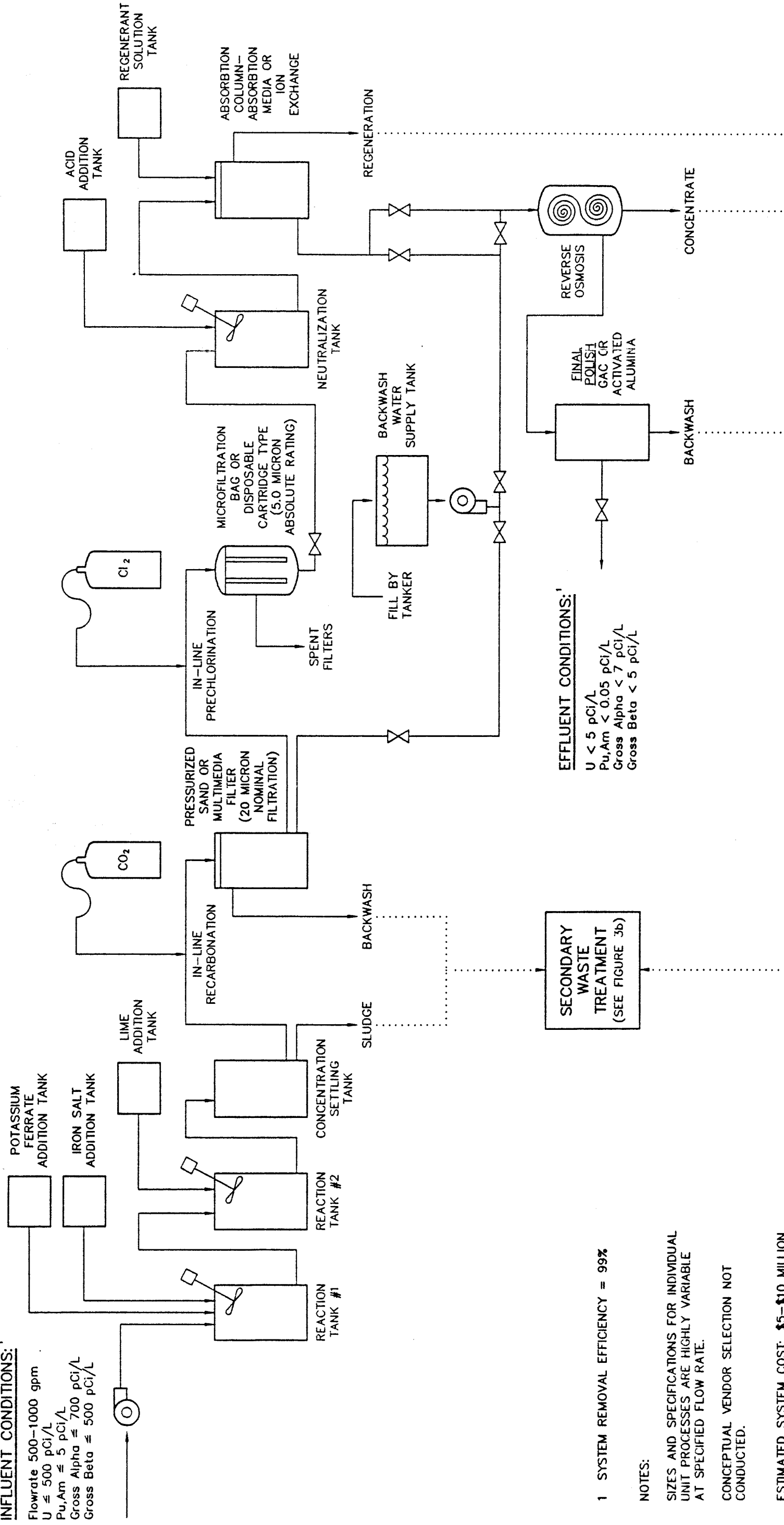
The above listed individuals met as a group to discuss the project scope, objectives and results and opinions were offered.

Eric W. Mank 11-1-94
Project Manager Date

- (1) Peer review is represented by at least two other professionals meeting for as long as necessary to review and discuss a draft report or other work product.
- (2) Work product is not WWE work product without a peer review.
- (3) Appraisals must be peer reviewed by individuals who have completed the ethics and standards course.

INFLUENT CONDITIONS:

Flowrate 500-1000 gpm
 $U \leq 500$ pCi/L
 $Pu, Am \leq 5$ pCi/L
Gross Alpha ≤ 700 pCi/L
Gross Beta ≤ 500 pCi/L



EFFLUENT CONDITIONS:

$U < 5$ pCi/L
 $Pu, Am < 0.05$ pCi/L
Gross Alpha < 7 pCi/L
Gross Beta < 5 pCi/L

1 SYSTEM REMOVAL EFFICIENCY = 99%

NOTES:

SIZES AND SPECIFICATIONS FOR INDIVIDUAL UNIT PROCESSES ARE HIGHLY VARIABLE AT SPECIFIED FLOW RATE.

CONCEPTUAL VENDOR SELECTION NOT CONDUCTED.

ESTIMATED SYSTEM COST: \$5-\$10 MILLION

WRIGHT WATER ENGINEERS, INC.
2490 W. 26TH AVE. SUITE 100A
DENVER, CO 80211
(303)480-1700

DRAWN _____ KAL
CHECK _____ EWM
DATE 11/10/94
JOB NO. 901-004.460

FIGURE 7a
**CONCEPTUAL TREATMENT SCHEMATIC
FOR RADIONUCLIDE REMOVAL
FULL SCALE SYSTEM, PRIMARY TREATMENT PROCESSES
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE**